Management of Powdery Mildew on Flowering Dogwood with Soybean Oil[1]

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Abstract

Soybean oil formulations developed in our laboratory were evaluated for control of powdery mildew on flowering dogwood *Cornus florida*. In a preliminary trial in a field nursery, two formulations, TNsoyl and TNsoy2 [0, 1 or 2% (v/v)], were applied to field-grown flowering dogwood at 2 wk intervals from June 10 until August 19. Soy oil-treated trees had less powdery mildew, higher net photosynthetic rate and growth rate than unsprayed trees, without apparent phytotoxicity. Leaves sprayed with Banner MAXX had less powdery mildew and higher photosynthetic rates than oil treated leaves. These same treatments applied the next year under more frequent rain showers did not provide satisfactory control. Newer soybean oil formulations using natural or food grade emulsifiers, were compared to three commercial botanical oil formulations and to SunSpray Ultra Fine Oil in greenhouse trials. All oil formulations provided some protective and eradicative control of powdery mildew. Photosynthesis of oil treated leaves was usually depressed, compared to controls, for several days but recovered. In greenhouse trials where the oil was not washed off by rain or irrigation, the oil residue was visible on leaves, reduced powdery mildew severity, and depressed photosynthesis for several weeks. In a second greenhouse trial, soybean oil formulations provided greater control if applied after rather than before initial inoculation.

Index words: *Erysiphe pulchra*, *Cornus florida*, botanical oil, biorational fungicide, vegetable oil, photosynthesis, phytotoxicity.

Species used in this study: *Cornus florida* (L.) seedlings, 'Rubra', 'Cloud 9'.

Chemicals used in this study: soybean oil, PF1025 (soybean oil), Golden Natural (soybean oil), Eco-oil (canola oil), SunSpray Ultra-Fine Oil, Banner MAXX, propiconazole.

Significance to the Nursery Industry

Powdery mildew has killed or made unsalable millions of nursery dogwood trees since the mid-1990s. The increased cost of fungicide usage for management of this disease has made dogwood production less appealing to many nurserymen. Mineral oil sprays during the dormant season have long been a cost effective control of overwintering insect and mite populations in nurseries and highly refined mineral oils can be used during the growing season to control some insects. Oils can also assist in control of some diseases, particularly powdery mildew. Resistance in target plant pathogens and insect pests is likely to occur following repeated exposure to a site-specific pesticide. Matheron and Porchas (28) noted reduced sensitivity of a powdery mildew pathogen to certain fungicides has already occurred on cucurbits (28). This research shows that the use of botanical oil sprays can reduce powdery mildew on flowering dogwoods by providing some protective and eradicative activities. Use of botanical oils in rotation with other pesticides is one approach to reducing the risk of resistance to pesticides. Botanical oils are relatively safe to the applicator and to the environment plus they are derived from renewable resources. They could play an important role in future IPM systems, especially those that rely less on conventional pesticides.

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Introduction

Flowering dogwoods (*Cornus spp.)* are important flowering deciduous trees in wholesale and retail nurseries and in the landscape. The 2007 U.S. Department of Agriculture Census of Agriculture reported over $6.5 billion sales of nursery stock in the United States (41). Deciduous flowering trees were reported to account for over $300 million of total nursery sales (43). In the 1998 Census of Horticultural Specialties, dogwoods accounted for approximately 8% of total sales of flowering deciduous trees (43). Wadl et al. concluded from the 1998 census that dogwood sales were especially important to retail and wholesale nursery sales in Alabama, California, Illinois, North Carolina, New Jersey, Oregon, Tennessee and Virginia, which accounted for nearly 75% of dogwood trees sold in the United States. Nurseries in Tennessee accounted for 23% of total dogwood sales.

Powdery mildew was rarely reported on flowering dogwood (*C. florida* L.) before 1994 (22), but since the mid-1990s has become the most damaging disease on flowering dogwood in the southeastern United States (30). Li et al. (25) reported that millions of dollars of flowering dogwood were destroyed and millions of cultivated seedlings lost their commercial value. As a result of fungicide input costs estimated at $\$800 \cdot acre^{-1} \cdot year^{-1}$ ($\$1,975 \cdot ha^{-1} \cdot year^{-1}$) for powdery mildew control, many small producers stopped flowering dogwood production. *Erysiphe pulchra* [(Cooke & Becke) U. Braum & S. Takamatsu] is the most common powdery mildew species infecting flowering dogwood in Tennessee (17, 30). Li et al. (26) reported that severe disease outbreaks caused stunted and distorted growth, death of twigs, and undesirable plant aesthetics. Windham et al. (45) reported that diseased trees grew slowly, had reduced flowering, delayed leaf bud break in the spring and unusually high rates of shoot death.

The use of oils (botanical and petroleum-derived) as adjuvants, inerts, and active pesticides has increased in the last 30–40 years (23). Mineral oils (petroleum-derived oils) have been used as dormant-season pesticide sprays on woody plants since the early 20th century. More highly refined horticultural mineral oils (narrow-range oils) can be used during the summer to reduce populations of mites (6, 7), aphids, mealybugs, leafhoppers, and scale insects (21). The mode of action on insects is thought to be primarily by suffocation (38), with death occurring within 24 hours (21). The highly refined mineral oil sprays have also been widely used to control diseases caused by *Mycoshaerella*, i.e. greasy spot on citrus and Sigatoka on banana (35). Furthermore, horticultural mineral oils have been reported to reduce the severity of powdery mildew on rose (18, 4), lilac (3), currant (19), and grape (34). Nicetic et al. (32) reported that sprays of horticultural mineral oil (0.3–0.5%, v/v in water) cured powdery mildew on greenhouse roses and prevented infection when applied at 7–14 day intervals. Walsh et al. (44) reported in 2008 that oils were effective in apple, cherry, cucurbit, grape, peach, rose, and tomato powdery mildew management programs; extremely useful in cherry and peach nurseries where disease pressure/resistance risk was extremely high; and usually the grower's best choice for controlling a mildew problem that appeared out of control. Hagan and Akridge (16) found that weekly sprays of 1% v/v SunSpray Ultra Fine Oil® controlled powdery mildew on flowering dogwood as effectively as tested synthetic fungicides, but there was less control in a year of severe powdery mildew pressure.

There is reluctance among growers to use horticultural mineral oils due to potential phytotoxicity. Oil induced damage may be physical (i.e. membrane damage) or due to suppression of plant functions (e.g. photosynthesis, respiration) (17). Zheng (46) reported that the most common phytotoxicity on ornamentals was oil-soaking spots in leaves that usually disappeared within a couple of weeks without apparent harm. Northover (35) stated that more severe phytotoxicity may be displayed as flecking of leaves, yellowing, and sometimes bronzing with dropping of older leaves; that phytotoxicity was greatly increased by photodegradation, higher oil deposits on leaves and higher temperatures; and that phytotoxicity from oil sprays was more frequent in drier climates and with accumulated oil spray residues from repeated sprays. Hagan et al. (16) reported that biweekly sprays of 1% v/v SunSpray Ultra Fine Oil damaged leaves of dogwood growing in full sun. They noted that sprays of this paraffinic oil at 1- or 2-week intervals during the growing season caused objectionable phytotoxicity to dogwoods grown in full sunlight. Martin et al. (27) reported that ≤ 2% SunSpray Ultra Fine Oil, fish and botanical oils generally caused little detectable phytotoxicity to grape leaves.

Oil sprays may also reduce photosynthesis of leaves, potentionally causing phytotoxicity and reducing growth. Our previous research with mite control on fruit trees showed that 1 and 2% soybean oil sprays generally reduced photosynthesis for 1 or 2 days, but had no effect 7 days after treatment (31). Martin et al. (27) reported that net CO_2 exchange of grapevines was lower than controls after six sprays of 2% SunSpray Ultra Fine Oil, fish or and botanical oils but not with 1% sprays. However, Lakso et al. (24) showed that powdery mildew (*Uncinula nectator*) reduced photosynthesis of infected apple leaves.

Growers have been under increasing pressure for the past decade to adopt sustainable pest control methods due to concerns of environmental contamination, for public health and development of pathogen resistance associated with use of synthetic pesticides. Pathogens have not been shown to develop to resistance to horticultural mineral oils (35). Crutchfield (5) suggested in the *Yearbook of Agriculture* that agriculture should promote environmental quality by supplying environmentally friendly products that substitute for petroleum products. The U.S. Environmental Protection Agency (39) issued a rule that established an exemption from normal pesticide registration for several botanical oils because they were relatively non-toxic to humans, non-persistent in the environment and had no significant adverse effects on the environment. Furthermore, botanical oils are a renewable resource.

Efficacies of botanical oils for disease control have been variable. Research in Canada (33) showed that emulsified sunflower, olive, canola, corn, and soybean oils provided over 99% control of powdery mildew on apple when applied one day before or one day after inoculation. They later reported that emulsified canola and soybean oils (1% v/v) were marginally effective against powdery mildew on grape (34) and that the two plant oils were active as preventative treatments and had an antisporulative effect on colonies of *Uncinula necator.* Pasini et al. (36) reported that canola oil provided satisfactory control of powdery mildew on rose in trials in Italy. Repeated sprays of canola oil (1) were found to be as effective as wettable sulfur or Rubigan in preventing powdery mildew on grape. Goodwin et al. (11) reported that canola oil (plus potassium bicarbonate) was a promising biorational treatment for powdery mildew on greenhouse cucumbers in Australia. Eco-oil® is a canola oil-based Australian commercial formulation with fractions of oils from *Melaleuca* spp. and *Eucalyptus* spp. It is reputed to have less risk of phytotoxicity at lower cost than other horticultural oils (9).

Commercial horticultural oil (petroleum- or plant- derived) typically contains 75–98% oil, 2–25% emulsifiers and sometimes other unknown proprietary additives (8). Adjutants affect emulsions, efficacy and phytotoxicity of the formulation but may also kill targeted organisms if sprayed alone. Irish et al. (20) reported that ten surfactants significantly reduced white rust on spinach compared with water controls. Matheron and Porchas (28) found that three adjuvants significantly reduced the severity of powdery mildew on muskmelon when applied alone. However, Grayson et al. (12) found that nine surfactants provided no control of powdery mildew on barley. Ebbon (8) stressed that additives to botanical oils should not be toxicological or ecotoxicological. Ebbon stated that it is 'probably safe to assume that products in widespread use as human food components … could be used as components of agricultural spray oils'.

We initially tested soybean, corn, canola and cottonseed methylated seed oils on peach for physiological effects (37) and to identify a botanical oil for future research. We chose soybean oil because it was effective, was the most abundant botanical oil produced in the United States (40) and had low levels of phytotoxicity to peach.

The objectives of this research were to evaluate emulsified soybean oil for 1) control of powdery mildew, 2) phytotoxicity, 3) effects on photosynthesis and tree growth of flowering dogwood, and 4) to develop new soybean oil formulations emulsified with all natural or food grade emulsifiers that might be used as biorational pesticides.

Materials and Methods

Field study 1. In an initial study, field-grown dogwood (*Cornus florida* 'Rubra') trees in a commercial nursery were left unsprayed (control), sprayed with 1 or 2% v/v of TNsoy1 [90% soybean oil emulsified with 10% Latron B-1956 Spreader-Sticker (Rohm and Haas Co., Philadelphia, PA)] or with TNsoy2b [90% soybean oil, 10% monolaurin (Lauricidin®, Med-Chem Laboratories, Inc., Irvine, CA)], or sprayed with 47 ml·100 liters^{-1} of Banner Maxx® [propiconazole (Syngenta Crop Protection, Inc., Greensboro, NC)] on June 10 and 24, July 9 and 15, August 4 and 19, and September 2, 1998. Treatments were arranged in a randomized complete block (RCB) design with eight trees per block in six replications. The soybean oil and emulsifier were premixed at least 30 minutes before adding to the spray water. The trees were sprayed to runoff using a Stihl SR-400 backpack mist blower (Stihl Inc., Virginia Beach, VA) that was shaken frequently to maintain the emulsion.

Net photosynthetic rate (Pn) of a recently fully-expanded upper leaf of an upper shoot from one tree in each plot was measured with an ADC-3 open system infrared gas analyzer (Analytical Development Company, Hoddesdon, UK) on July 16, one day after the fourth treatment. Foliar Pn rates were also measured on August 18 (one day before the sixth treatment) and on August 20 (one day after treatment).

Severity of powdery mildew infection of foliage of each tree was rated using the following scale: 0 = healthy, 1 = 1–2%, 2 = 3–9%, 3 = 10–24%, 4 = 25–49%, 5 = 50–99%, 6 = 100% of foliage surface displaying symptoms or signs of powdery mildew. Tree growth was evaluated by measuring the trunk diameter (caliper) and height of each tree on June 10 and September 2.

Field study 2. In 1999, field grown dogwood (*C. florida* 'Rubra') trees in a nursery near McMinnville were left unsprayed (control); sprayed with 1, 1.5, 2, or 2.5% v/v of TNsoy1 (90% soybean oil); or sprayed with Banner MAXX as described in Field Study 1. The trees were sprayed five times at approximately two-week intervals from June 22 until August 26. Leaf Pn rates were measured on July 1, 16, and 28, and August 14 and 27 as described in Expt. 1. Powdery mildew incidence was rated with the scale described above. Treatments were arranged in a RCB design with five replications.

Formulation development. Mixtures of adjuvants, water and refined soybean oil were initially prepared in our laboratory to evaluate emulsion stability. The goal was to indentify an emulsifier that would maintain a stable soybean oil emulsion in water, especially an emulsifier that was naturally occurring or approved for the food industry. Refined soybean oil (food-grade) was used as the active ingredient in all formulations. Names of the formulations developed are prefixed by TNsoy. Adding the soybean oil and an adjuvant separately to spray water generally resulted in less emulsification than if the adjuvant and oil were mixed for greater than 30 minutes before adding to water.

Refined soybean oil was mixed with 1, 5 or 10% v/v with the adjuvants calcium stearate, calcium stearoyl lacylate, calcium dodecylbeneze sulfontae, sodium lauryl sulfate, glycerol monostearate, triglycerol monostearate, sorbitan monostearate, Latron B-1956 Spreader Sticker, lecithin, monolaurin (Lauriciden), Teric N4 surfactant and Termul 1284 surfactant (Huntsman Corporation, Woodsland, TX), and Yucca Aide 10 and 20 (Desert King International, Chula Vista, CA) in 150 ml glass vials. An aliquot (5 ml) of the oil/adjuvant was placed in capped nalgene bottles containing 95 ml of water. Bottles containing the mixtures were then placed in a shaker for one minute at 12 rpm. Pictures were taken prior to shaking and at one, two and five min after shaking. The mixtures that remained in emulsion for greater than two minutes were placed in cold storage at 36F (2C) overnight to assess emulsion stability over time and under cool temperatures.

Greenhouse study 1. Seedling flowering dogwoods were potted in pine bark media in #5 containers and grown in a greenhouse in late summer and fall. They were sprayed with sulfur until a week prior to starting the experiment. The trees were taken outdoors and treatments sprayed to runoff on September 13, 2000, using a backpack mist sprayer. The trees were treated with water (control), 1.5% v/v of TNsoy1, TNsoy3 (94.2% soybean oil, 4.2% Teric N4 and 1.6% Termul 1284), TNsoy4 [92% soybean oil, 4.2% Teric N4 and 1.6% Termul 1284, 1.6% *Eucalyptus* oil, and 0.5% *Melaleuca* oil (Melaleca Inc., Knoxville TN)], TNsoy5 [90% soybean oil, 10% Yucca Ag-Aide10, (Desert King Int'l, Chula Vista, CA)], TNsoy6 [90% soybean oil, 10% Yucca Ag-Aide20 (Desert King Int'l)], PF1025 [Pammark Farms Ltd., Marysville, OH], Golden Natur'l® [93% soybean oil, Stoller Enterprises Inc., Houston, TX], Eco-oil® [Organic Crop Protectants, PTY LTD, 42 Halloran St Lilyfield 2040 NSW, Australia], or SunSpray Ultra-Fine Oil® [*n*C21 paraffinic oil, Sonoco, Philadelphia, PA]. Golden Natur'l and PF1025 are company-developed soybean oil-based formulations. Eco-oil is a canola oil-based formulation with fractions of essential oils from *Melaleuca* spp. and *Eucalyptus* spp. Botanical adjuvants were used in TNsoy5 and TNsoy6 to produce all botanical-based formulations.

The trees were distributed in the greenhouse after treatment in a RCB design with five replications. Diseased flowering dogwoods were distributed around the block of study trees to provide a continuous source of inoculum of the causal fungus *E. pulchra*. Another group of trees in the greenhouse were sprayed with the above treatments on September 20, six days after initial pathogen exposure and arranged in a RCB design with five replications. Treated dogwoods were rated the day before exposure to powdery mildew and on October 4, 17, and 26 for powdery mildew using the previously described scale. Newly fully expanded, healthy leaves were tagged, and Pn rates were measured before treatment and on September 14 and 21 and on October 2, 10, 21 and 24. Photosynthesis measurements were made between 10:00 AM and 3:00 PM when Photosynthetically Active Radiation was above the light saturation point (>800 $\mu mol \cdot m^{2-1} \cdot s^{-1}$). The same leaf was measured throughout the Pn sampling period.

Greenhouse study 2. Greenhouse trials were conducted in 2002 to evaluate the effects of other soybean oil formulations on powdery mildew control and aesthetics of flowering dogwood. Container (#5) grown 'Cloud 9' trees were sprayed on October 3 with water (control), 1.5% of TNsoy20 (96.8% soybean oil, 1.5% Teric N4 and 01.7% Termul 1284), TNsoy21 (97% soybean oil, 3% Lauriciden), TNsoy22 (85% soybean oil, 15% lecithin), TNsoy23 (77.5% soybean oil, 15% lecithin and 7.5% MD experimental adjuvant), TNsoy24 (85% soybean oil, 7.5% lecithin and 7.5% MD), TNsoy25 (85% soybean oil, 15% Latron B-1956), or Golden Natur'l. Trees were arranged on greenhouse benches in a RCB design with six replications. Flowering dogwood trees severely infected with *E. pulchra* were moved into the greenhouse the day after treatment. Another group of 'Cloud 9' trees were sprayed with the above treatments on October 8, four days after initial exposure to powdery mildew, and placed on benches adjacent to the previous trial. The trees were arranged in a RCB design with six replications. Powdery mildew was rated October 23 and November 5 with a different scale (1): 1 = 0%, 2 = 1–3%, 3 = 4–6%, 4 = 7–12%, 5 = 13–25%, 6 = 26–50%, 7 = 51–87%, and 8 = 88–100% of leaves with evidence of powdery mildew. Phytotoxicity was rated on November 19 using a five-point rating scale (6): 1 = no visible damage, 2 = slight yellowing on some leaves, 3 = moderate yellowing on most leaves, 4 = burn without dieback, and 5 = burn with dieback. Net photosynthetic rates were measured as previously described.

Oil residue left by the formulations on flowering dogwood leaves was determined by randomly selecting five treated leaves from each tree on October 15. Each leaf was submersed in 20 ml of chloroform in a porcelain dish for 30 sec, and the solution was filtered with Whatman filter paper. The procedure was repeated two more times per leaf. The chloroform was evaporated under a hood, and the weight of oil/wax was determined per leaf cm^2.

Data analysis. Data were analyzed by Proc GLM using SAS (SAS 9.2, SAS Institute Inc., Cary, NC). Mean separation for data in field trials was determined by Duncan's multiple range test (P = 0.05) in field trials and by Tukey's Studentized Range Test (P = 0.05) for greenhouse trials.

Results and Discussion

Field study 1. In 1998, field-grown dogwoods treated biweekly with 1 or 2% soybean oil formulations had less powdery mildew throughout the observation period (July 9 until September 2) than unsprayed trees. There was interaction ($P \leq 0.05$) among treatments and the amount of powdery mildew on different dates (Fig. 1). All soybean oil-treated trees had less than 10% of leaf surface colonized one month (July 9) after the initial application, compared with 25% of foliage of untreated dogwoods (Fig. 1). While the two soybean formulations provided similar control (P > 0.05), the TNsoy2b visually appeared less rain-fast. The 2% TNsoy1 (soybean oil/Latron B-1956) sprays provided better control than the 1% rate ($P \leq 0.01$); however, the 2% rate of TNsoy2b (soybean oil/Lauridicin) provided similar control as the 1% rate. Although the 2% TNsoy1 gave similar control of powdery mildew as Banner MAXX on July 9, the synthetic fungicide controlled the disease better for the remainder of the growing season.

Hagan et al. (15) reported that dogwood leaves treated with 1% v/v SunSpray Ultra-Fine Oil had <7% of leaves colonized by *E. pulchra*, compared with 75% colonization on untreated trees. They also reported that Banner MAXX provided more consistent control of powdery mildew than SunSpray Ultra-Fine Oil. Martin et al. (27) reported that 1% crude soybean oil, and fish oils SunSpray Ultrafine oil, were at least as effective as the standard fungicide quinoxifen for controlling powdery mildew on grapevines, with soybean oil being the most effective.

In this trial, Pn rates were first measured on August 5, a day after the fifth spray. Trees sprayed with 1 or 2% of TNsoy1 or TNsoy2b had > 35% higher Pn rates than untreated controls on the day after treatment, perhaps due to suppression of powdery mildew (data not shown). Martin et al. (27). Leaf Pn rates were measured again on August 18, the day before the next treatment (14 days after previous treatment) and again on August 20. There was no interaction of the effect of treatments Pn rates across dates, thus mean Pn rates on different dates are shown in Fig. 2. Photosynthetic rates of TNsoy2b treated trees were higher (P = 0.004) across the sampling dates than for trees sprayed with water or TNsoy1. Trees treated with Banner MAXX consistently had the highest Pn rates, probably due to greater powdery mildew control. Phytotoxicity was not observed on any trees with seven soybean oil or Banner MAXX sprays during the growing season. Synthetic pesticides have been reported to reduce Pn (2); however, Ferree et al. (10) reported that the majority of pesticides they tested had little effect on apple leaf Pn rates. High mite populations can reduce photosynthesis, and soybean oil sprays at these rates during the growing season can reduce mite populations and, thus,

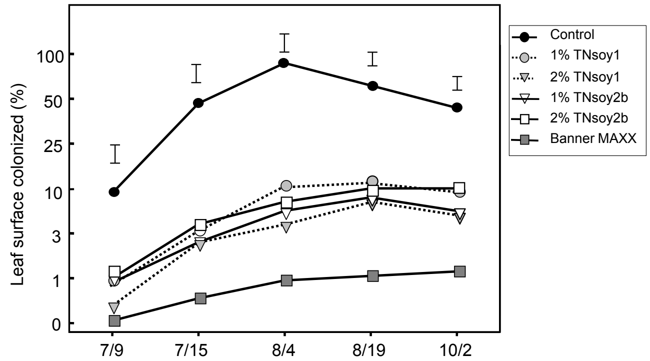

Fig. 1. Powdery mildew infection of field-grown nursery flowering dogwood trees treated with soybean oil formulations or Banner MAXX sprayed biweekly throughout the summer. Data are means based on eight trees per block and six replications on each date, LSD at *P* < 0.05.

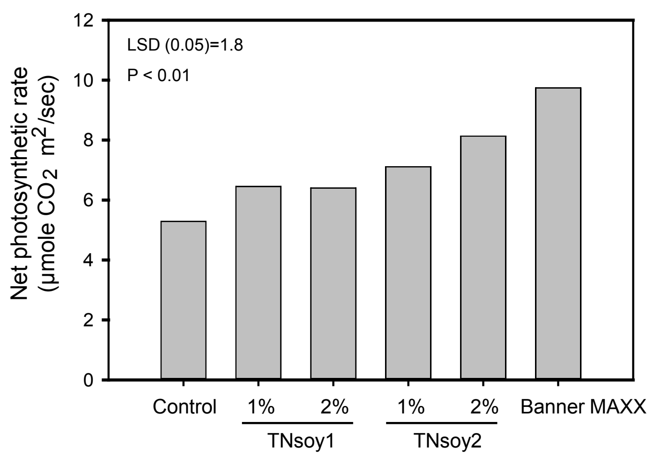

Fig. 2. Influence of biweekly sprays of soybean oil formulations or Banner MAXX on leaf net photosynthetic rates of flowering dogwood trees in a field-grown nursery. Data are means based on one tree per block and six replications on each date.

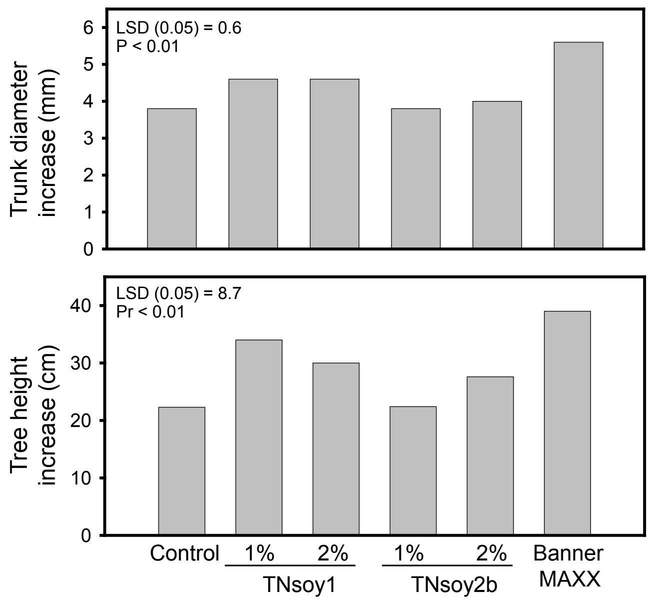

Fig. 3. Biweekly sprays of soybean oil formulations or Banner MAXX influence on growth of field-grown nursery flowering dogwood trees. Data are means based on eight trees per block and six replications on each date.

affect photosynthesis (31). However, high mite populations were not noted during the trial.

Dogwoods sprayed seven times with 1 or 2% TNsoy1 had more growth in tree height and trunk caliper than unsprayed trees (Fig. 3). TNsoy2 (2%) treated trees had greater increase of tree height. Latron B-1956 had been had been our standard emulsifier of soybean oil in earlier physiology trials, but this trial indicates that other emulsifiers may perform as well or better. Banner MAXX-treated trees had the greatest increases in tree height and trunk caliper, probably due to generally better powdery mildew control and higher Pn rates of treated leaves.

Field study 2. In the following year, neither biweekly sprays of TNsoy1 (1.0–2.5% v/v) nor Banner MAXX significantly reduced the incidence of powdery mildew on field-grown dogwood trees compared to untreated trees (data not shown). Most soybean oil treatments resulted in less than 10% leaf surface area infected after a month, compared to more than 50% surface area infection on water sprayed plants. Rains were frequent during the spring/early summer and infection had probably occurred prior to test initiation. Gubler and Koike (14) recently stated that horticultural or plant based oils were the treatment of choice to eradicate mild to moderate powdery mildew infections on ornamentals.

The first application (June 22) of TNsoy1 influenced net photosynthesis (Pn) rates of dogwood leaves when measured on July 1 ($Y = 3.70 + 2.90x - 1.19x^2$, $P = 0.002$). Higher Pn rates were noted on plants sprayed with 1.0 and 1.5% oil than with 2 or 2.5% oil rates (data not shown). Treatments did not affect Pn rates on the last measurement date. It should be noted that the weather was dry at that time, the trees appeared unhealthy, and Pn rates were relatively low; thus, the trees were not measured for overall growth. Although five applications of 2.5% TNsoy1 did not cause visible phytotoxicity, 2.0 and 2.5% TNsoy1 tended to reduce Pn over the study period compared to 1 or 1.5% rates.

Formulation development. Yucca Aide 10, Yucca Aide 20, Teric N4, Termul 1284, lecithin, and Lauriciden were selected from the laboratory trials for further evaluation as an adjuvant with soybean oil. Calcium stearate, calcium stearoyl lacylate, calcium dodecylbeneze sulfonate, sodium lauryl sulfate, glycerol monostearate, triglycerol monostearate, sorbitan monostearate were discarded, usually because they did not maintain soybean oil in emulsion in water for at least two minutes.

Greenhouse study 1. Botanical oil formulations were evaluated in greenhouse conditions for effects on *E. pulchra* and on flowering dogwood Pn rates and phytotoxicity. All formulations of botanical (soybean and canola) oils and the SunSpray Ultra-Fine Oil reduced powdery mildew incidence compared to controls for up to 46 days (October 26) in the greenhouse ($P \leq 0.01$, data not shown). In this trial, the trees were grown in a greenhouse with drip irrigation, thus spray residues were not weathered by rain.

The effects of timing of treatment for each formulation on powdery mildew colonization on October 5 and 17 (25 and 37 days, respectively, after inoculation) are shown in Fig. 4. Data for ratings on the two dates were pooled and analyzed. There was significant interaction between timing of application and chemical treatment ($P \leq 0.01$). Trees sprayed with botanical oils or SunSpray Ultra-Fine Oil before inoculation had similar powdery mildew colonization as trees sprayed after inoculation ($P = 0.11$). All botanical oil sprays and SunSpray Ultra-Fine Oil sprays applied either before ($P \leq 0.01$) or after ($P \leq 0.01$) inoculation reduced colonization. Golden Natur'l provided less preventive or eradicative control than the commercial formulations Eco-oil (canola oil plus oil from *Melaleuca* spp. and *Eucalyptus* spp.) or SunSpray Ultra-Fine

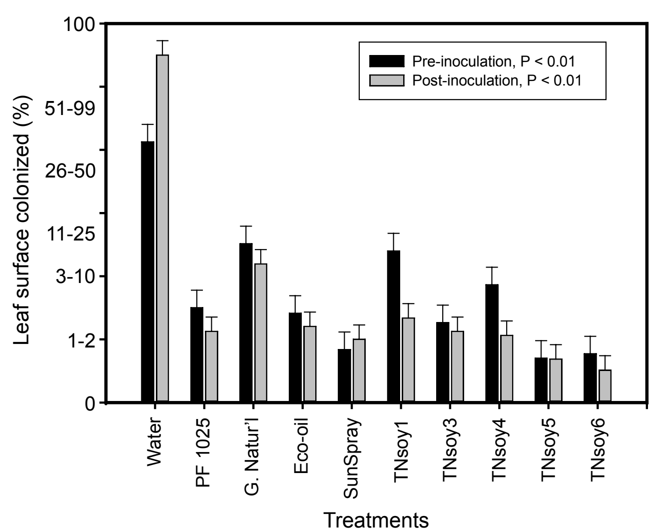

Fig. 4. Effects of oil formulations (1.5% v/v) sprayed pre- and post-inoculation with *E. pulchra* on powdery mildew colonization on flowering dogwood leaves in a greenhouse environment. Treatment means are from combined ratings made 25 and 37 days after inoculation and of five replications, ± 1 SE. The pre and post inoculation treatments did not differ ($P < 0.05$) but interaction with formulations was significant ($P < 0.01$).

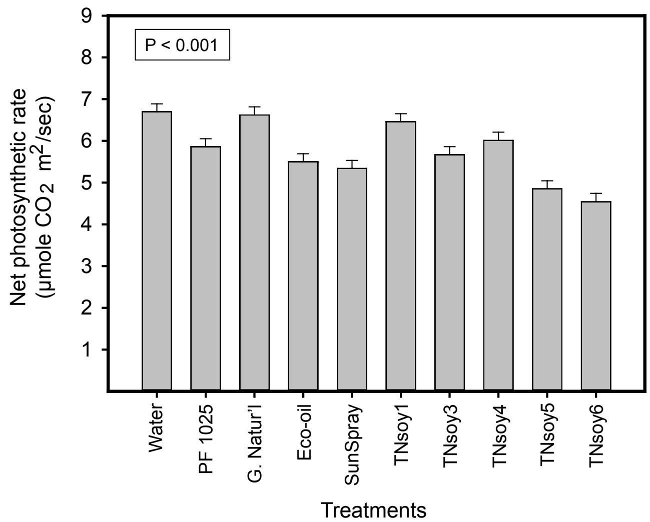

Fig. 5. Effects of oil formulations (1.5% v/v) sprayed pre- and post-inoculation with *E. pulchra* on 'Cloud 9' flowering dogwood photosynthetic rates (Pn) in a greenhouse environment. Means are of five replications and from combined data from the first day after spraying treatments pre- or post-inoculation, ± 1 SE.

Oil. Mean separation by Tukey's Studentized Range Test ($P = 0.05$) indicated that post inoculation application of botanical oil treatments, except Golden Natur'l, provided similar control as SunSpray Ultra-Fine Oil. All post inoculation treatments except Golden Natur'l resulted in <10% of leaf area colonized by powdery mildew. Addition of *Melaleuca* and *Eucalyptus* oils to the TNsoy3 formulation to create TNsoy4 did not improve efficacy. Leaves sprayed with TNsoy5 and TNsoy6 (soybean oil with adjuvants Yucca Ag-Aide 10 and Yucca Ag-Aide 20, respectively) were almost free of powdery mildew (< 1% leaf surface) on October 17 but the formulations were more difficult than the other formulations to maintain in emulsion.

Timing of spray application relative to powdery mildew exposure did affect not leaf Pn rates (data not shown). Although all trees sprayed with oil treatments had Pn rates 5–34% lower than control trees the day after treatment, only trees sprayed with 1.5% SunSpray Ultra-Fine Oil, TNsoy5 or TNsoy6 had significant reductions ($P = 0.05$) of 27–34% (Fig. 5). Analysis of combined data from the day after treatment date until October 24, indicated that trees sprayed with 1.5% Golden Natur'l, PF1025, TNsoy1, or TNsoy4 had similar Pn rates as controls ($P = 0.05$). However, trees sprayed with 1.5% Eco-oil, SunSpray Ultra-Fine Oil, TNsoy5 or TNsoy6 had lower ($P = 0.05$) Pn rates (18, 21, 28, and 32%, respectively) than controls for the time interval.

Greenhouse study 2. In this trial, the amount of powdery mildew colonization on leaves was less ($P \leq 0.01$) at 19 days after exposure to inoculum when soybean oil formulations (1.5% v/v) were applied post-inoculation than applied pre-inoculation (Fig. 6). There was again interaction between effectiveness of formulations and time of application ($P \leq 0.01$). Trees sprayed pre-inoculation with Golden Natur'l, TNSOY20 (adjuvants = 1.5% Teric N4 and 01.7% Termul 1284 v/v), TNSOY22 (adjuvant =15% lecithin v/v), or TNSOY25 (adjuvant =15% Latron B-1956 v/v) reduced ($P \leq 0.05$) powdery mildew severity compared to the control trees, however TNsoy21 and TNsoy24 had had no significant effects. All formulations sprayed four days after exposure to *E. pulchra* reduced disease severity compared to controls ($P \leq 0.01$).

Oil formulations had no significant effects on Pn rates the day after treatment or on later observation dates. Slight differences ($P = 0.05$) of Pn rates among treatments were found when data from the 4th, 14th and 26th of October of pre- and post-inoculation treatments were pooled (Fig. 7). Trees treated with TNsoy20 had slightly higher Pn rates than other treatments.

All treatments, except TNsoy25 (with 15% Latron B-1956), left more oil/wax residue on leaves than controls at one week after treatment (Fig. 8). Latron B-1956 is a spreader-sticker and was expected to leave more residue on the leaves, thus data from that treatment may be unreliable. In a separate trial, peach leaves sprayed with TNsoy25 had three-fold more oil/wax residue compared to control leaves one hour after treatment (unpublished data). TNsoy20 (Teric N4, Termul 1284 adjuvants) treated leaves had the most residue.

Leaves of untreated flowering dogwood were still healthy when rated November 19 compared with those from the oil-treated plants, which showed slight to moderate yellowing (data not shown). Leaves sprayed with TNsoy22 (with 15% lecithin) had significantly more yellowing than control leaves and relatively high residues levels. TNsoy21 (97% soybean oil, 3% Lauriciden) sprays also caused significant yellowing of foliage but left less residue on leaves.

Summary. Soybean oil sprays leave oil residues on flowering dogwood leaves can affect *E. pulchra* colonization as well as leaf physiology. Repeated sprays of up to 2% emulsified soybean oil reduced *E. pulchra* in field nurseries in two trials without apparent phytotoxicity. Dogwood leaf net photosynthesis was increased in the first trial, probably due to suppression of dogwood colonization. Banner MAXX provided better powdery mildew season-long control in field

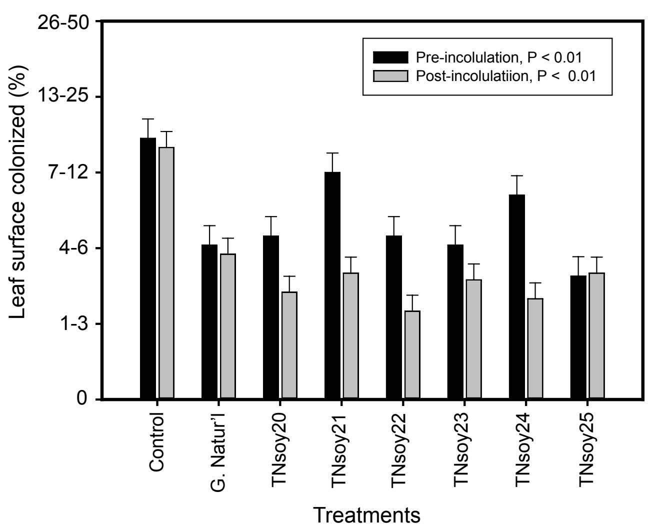

Fig. 6. Effects of soybean oil formulations (1.5% v/v) sprayed pre- and post-inoculation with *E. pulchra* on powdery mildew colonization on 'Cloud 9' flowering dogwood leaves in a greenhouse environment. Means are from data on October 23 (19 days after inoculation) and six replications, ± 1 SE.

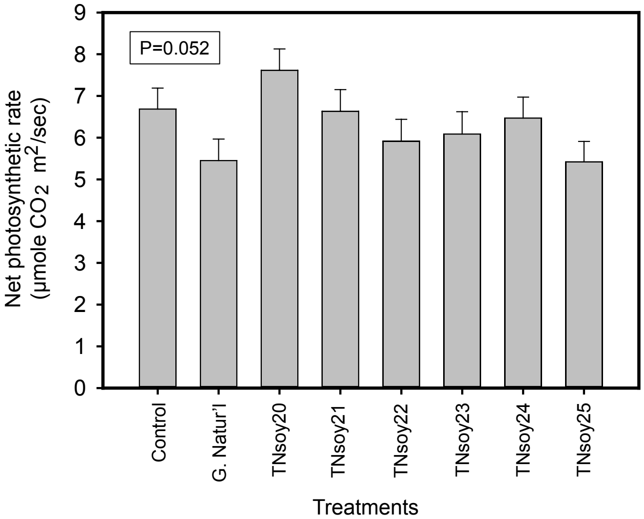

Fig. 7. Effects of soybean oil formulations (1.5% v/v) on net photosynthetic rates (Pn) of 'Cloud 9' flowering dogwood leaves in a greenhouse environment when sprayed pre- and post-inoculation of *E. pulchra*. Means are from pooled data from the 4th, 14th and 26th of October and six replications, ± 1 SE.

nurseries and higher leaf Pn rates than soybean oil sprays. Repeated sprays of 2 or 2.5% soybean oil in the second field trial resulted in slightly lower Pn rate than 1 or 1.5% sprays. If there is no rain/irrigation to wash off the oil, the oil may be retained on leaves and is likely to accumulate with repeated sprays. Accumulated oil residues may further depress photosynthesis over time or cause injury. We currently suggest that the formulations be applied at 1.5% v/v; future research should evaluate lower concentrations.

Adjuvants have long been used to improve the stability, spread, rain-fastness, efficacy, etc. of pesticides. The performance of a pesticide is usually described without a separate discussion of its adjuvant, which is often a proprietary blend. Only the soybean formulations were tested, not the adjuvants by themselves, because we were more interested in the performance of the soybean oil formulations. The emulsifiers affected soybean oil formulation emulsion stability, efficacy, phytotoxicity, and flowering dogwood photosynthesis. Besides testing the properties and efficacies of botanical oil formulations, future trials may determine the contribution of emulsifiers to disease control when used alone.

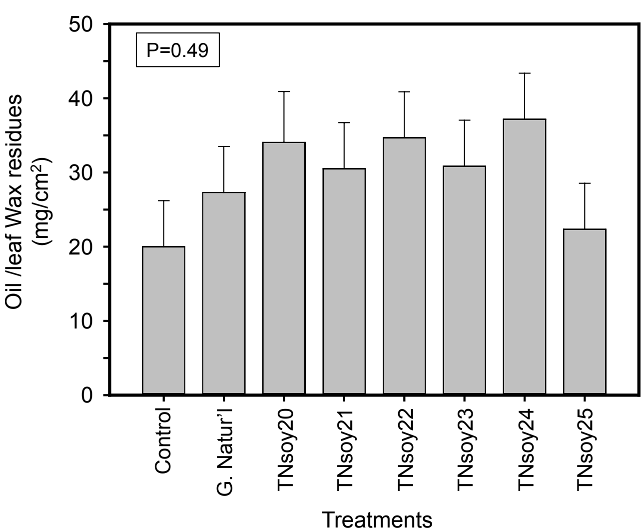

Fig. 8. Oil residues/leaf wax on leaves of greenhouse grown 'Cloud 9' flowering dogwood trees seven days after spraying soybean oil formulations (1.5% v/v).

The above series of studies show that emulsified soybean oil can function as a biorational pesticide to aid in the control of powdery mildew on flowering dogwoods. The greenhouse trials demonstrated some preventive and curative activity by soybean oil against powdery mildew. Northover and Schneider (34) reported that mineral and plant oil had excellent pre-lesion curative action when applied 3 days after inoculation, some post-lesion spray smothering of lesions, and excellent antisporulation for powdery mildew on grape vines. The formulations tested did not provide season-long control of powdery mildew or adequate control in a rainy season, but may be an useful management tool to use in concert with fungicides to avoid selection of resistant powdery mildew populations. Soybean oil sprays may best be used in an integrated pest management strategy and in resistance strategies. McGarth and Shishkoff (29) recently stated that curcubit growers desiring to maintain their level of control of powdery mildew needed to use biocompatible fungicides (i.e. JMS Stylet-Oil®) in combination with conventional fungicides.

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