Synthetic and Biorational Fungicides Compared for the Control of Three Foliar Diseases of Flowering Dogwood[1]

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Abstract

The biorational fungicides Neem Concentrate, SunSpray Ultra Fine Oil®, Rhapsody® were compared with the synthetic fungicides Eagle® 40W, Immunox®, Liquid Systemic Fungicide®, and 3336™ 50W for the control of spot anthracnose, Cercospora leaf spot, and powdery mildew on 'Rubra' flowering dogwood. In 2003, 2004, and 2005, fungicide treatments were applied at label rates at 1- and/or 2-week intervals over a period that coincided with the onset spot anthracnose and powdery mildew but before the appearance of Cercospora leaf spot. With few exceptions, the synthetic fungicides gave better control of the above diseases than biorational fungicides. Eagle 40W, Immunox, Liquid Systemic Fungicide, and 3336 50W gave equal control of the bract and leaf spot phases of spot anthracnose. Most notable was the carryover of control of the bract spot phase of spot anthracnose into the spring of the following year with the synthetic fungicides. While some control of spot anthracnose was seen in at least one year with the biorational fungicides, none was as effective as the synthetic fungicides. In 2003 and 2004, Neem Concentrate, SunSpray Ultra Fine Oil, and Rhapsody, when applied weekly controlled powdery mildew as effectively as the synthetic fungicides. Efficacy of the biorational fungicides declined under severe powdery mildew pressure in 2005. While Cercospora leaf spot development was slowed by the Eagle 40W, Liquid Systemic Fungicide, and 3336 50W, the biorational fungicides as well as the retail product Immunox also gave some control. An objectionable mottling of the leaves was noted on the flowering dogwood treated with SunSpray Ultra Fine Oil. Control of these diseases with the synthetic or biorational fungicides did not result in an increase in tree height or trunk diameter. While the biorational fungicides demonstrated sufficient efficacy for controlling powdery mildew on flowering dogwood in the landscape, they often failed to provide the level of control of this disease as well as spot anthracnose and Cercospora leaf spot needed to produce quality container- and field-grown nursery stock.

Index words: *Cornus florida*, *Elsinoe corni*, *Erysiphe pulchra*, *Pseudocercospora cornicola*, 3336 50W, Immunox, Eagle 40W, SunSpray Ultra Fine Oil, Neem Concentrate, Liquid Systemic Fungicide, Rhapsody, thiophanate-methyl, myclobutanil, propiconazole, paraffinic oil, *B. subtilis* QST 713, clarified extract of neem oil, chemical control.

Species used in this study: *Cornus florida* 'Rubra'.

Significance to Nursery Industry

When applied on a 2-week schedule at label rates, commercial products Eagle® 40W and 3336™ 50W as well as retail products Liquid Systemic Fungicide® and Immunox® were often equally effective in controlling of spot anthracnose and powdery mildew as well as slowing the spread of Cercospora leaf spot on 'Rubra' flowering dogwood. Biorational fungicides Neem Concentrate, SunSpray Ultra Fine Oil®, and Rhapsody® were usually less effective in controlling spot anthracnose and Cercospora leaf spot than Eagle 40W, Immunox, Liquid Systemic Fungicide, and 3336 50W. When applied on a 1-week schedule, the level of powdery mildew control maintained by the biorational fungicides was often comparable to the synthetic fungicides applied at 2-week intervals. Due to the apparently high phytotoxicity risk, SunSpray Ultra Fine Oil should not be applied to flowering dogwood growing in full sun. While Eagle 40W, Immunox, Liquid Systemic Fungicide, and 3336 50W gave superior disease control, repeated applications of these fungicides over an extended time period may result in a control failure due to resistance. The risk of a resistance-related control failure, particularly with powdery mildew, is higher for the benzimidiazole type fungicide 3336 50W than triazole [EBI or ergosterol biosynthesis inhibitor] fungicides Eagle 40W, Immunox, and Liquid Systemic Fungicide. Use of each of the above class of fungicides should be restricted to no more than ½ of the total number of fungicide applications to a given crop per production cycle or growing season. While alternating a benzimidiazole and triazole fungicide is acceptable, rotating or tank-mixing a contact synthetic or possibly biorational fungicide with a benzimidiazole and/or triazole fungicide is the preferred resistance avoidance strategy.

Introduction

Across the southeastern United States, flowering dogwood (*Cornus florida* L.) are a staple in landscape and commercial plantings making them a major commodity of field and container nurseries. Showy bracts, attractive fall foliage color, red fruit clusters, and a widespread adaptability account for the popularity of this tree with consumers and landscapers.

Fungal diseases often have a detrimental impact on the appearance and health of flowering dogwood in the nursery and landscape (5). Spot anthracnose, caused by *Elsinore corni* Jenkins and Bitanic., may badly deface and distort flower bracts and juvenile leaves, particularly on trees grown in full sun but does not appear to reduce overall tree vigor (1, 10). Powdery mildew, which is caused by *Erysiphe pulchra* (Cook & Becke) U. Braum & S. Takamatsu comb. nov. [syn. = *Microsphaera pulchra*, *M. penicillata*], may be the most damaging disease on flowering dogwood in the nursery, landscape, and forested sites across the Southeast (5, 9, 13, 18, 23). Although disease-related damage on established flowering dogwood appears largely cosmetic, slowed shoot growth and seedling death have been attributed to severe powdery

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mildew outbreaks (11, 14, 21). Previously, Cercospora leaf spot, caused by *Pseudocercospora cornicola* (Tracy & Earle) Guo & Lin [syn = *Cercospora cornicola*] was not recognized as a damaging disease of flowering dogwood (3, 5). However, Cercospora leaf spot-damaged trees often too heavily defoliated by early October for any fall color display (4, 7).

Control of this disease complex presents homeowners and landscape managers with a significant challenge in maintaining the beauty and vigor of flowering dogwoods. While a few flowering dogwood cultivars have good resistance to powdery mildew and/or spot anthracnose, the vast majority in landscape plantings are either native seedling trees or a cultivar susceptible to one or both diseases (9, 15). Preliminary results of Alabama studies (4, 8) indicate that several popular cultivars of flowering dogwood are highly susceptible to Cercospora leaf spot, while Stellar® Series hybrid dogwood cultivars as well as 'Pigmy', 'Red Pigmy', and 'Pumpkin' flowering dogwoods may have partial resistance. However, Stellar hybrid dogwood cultivars are not well adapted for landscape use in Central and South Alabama (8, 9).

Since the majority of flowering dogwoods in landscape plantings are susceptible to the above diseases, fungicides are a possible control option. While very few studies concerning the fungicide efficacy for the control of spot anthracnose on flowering dogwood have been published (1), EPA-registered synthetic fungicides include one or more formulations of Heritage® 50W [azoxystrobin]; Daconil Ultrex® and Daconil Weather Stik® [chlorothalonil]; Kocide® 3000 [copper hydroxide]; Dithane® M-45 [mancozeb]; Eagle 40W and Immunox [myclobutanil]; Bayer Disease Control for Roses, Shrubs and Flowers® [tebuconazole]; as well as 3336™ 50W, 3336™ 4.5F, and Halt® [thiophanate-methyl] (1, 10). Effective control of powdery mildew on container or field grown flowering dogwood has been obtained with the synthetic fungicides Heritage 50W [azoxystrobin] (11, 14), Phyton 27® [copper sulfate pentahydrate] (14), Eagle® 40W (11, 16, 22), Banner MAXX® [propiconazole] (22), 3336 4.5F (11, 14), Spectro® [thiophanate-methyl + chlorothalonil] (22), Compass™ 50W [trifloxystrobin] (11, 22), and the experimental triflumizole (22). Among biorational fungicides, good control of powdery mildew on flowering dogwood have been obtained with SunSpray Ultra Fine Oil® (11, 16), Armicarb® [potassium bicarbonate (baking soda)] (11), and several household soaps (14). While Armicarb® controlled this disease (14), a similar product failed to protect dogwood from powdery mildew (16, 22). Household soaps Ajax® and Equate®, which are not EPA registered-pesticides, were nearly as effective in controlling this disease as synthetic fungicides (14). In addition to improved tree aesthetics associated with powdery mildew control on flowering dogwood, significant increases in trunk diameter and tree height have also been seen with synthetic fungicides (11, 14). Since Cercospora leaf spot has never before caused concern, data concerning the efficacy of fungicides for the control of this disease have never been generated.

A field trial was initiated in 2003 to assess the efficacy of selected synthetic and biorational fungicides, including products marketed for home landscape use, for the control of spot anthracnose and powdery mildew on flowering dogwood in a simulated landscape setting. In addition, the residual effect of a spring-early summer fungicide program on the onset and development of Cercospora leaf spot later in the growing season and impact of fungicide treatments on flowering dogwood growth was also evaluated.

Materials and Methods

Tree maintenance. In February 2001, 'Rubra' flowering dogwood were transplanted from #5 containers into a Benndale sandy loam soil (≤ 1% OM) at the Brewton Agricultural Research Unit (USDA Hardiness Zone 8a), which is located approximately 45 miles northeast of Pensacola, FL. Prior to planting, soil fertility and pH were adjusted according to the results of a soil fertility assay. Newly established trees were mulched with 1 to 2 cm (0.5 to 1.0 in) of aged pine bark. Fresh bark mulch was evenly distributed on March 5, 2003, and March 10, 2004, around the base of each tree. A drip irrigation system was installed at planting and the trees were watered as needed. On February 25 and March 3, 2003, 85 g (2.9 oz) of murate of potash (0–0–60 K_2O) and 62 g (2.1 oz) of 16N–4P_2O_5–8K_2O fertilizer, respectively, was distributed around the base of each tree. On March 9, 2004, 57 g (0.2 lb) of super phosphate (0N–46P_2O_5–0K_2O) was evenly distributed around the base of each dogwood, while on April 12, 2005, 21 g (0.7 oz) of ammonium nitrate (33N–0P_2O_5–0K_2O [NH_4NO_3]) was spread over the bark mulch around each tree. A broadcast application of the pre-emergent herbicides Gallery® at 0.68 kg ai/ha (1 lb/A) [isoxaben, Dow AgroSciences LLC, Indianapolis, IN] and Surflan® at 2.2 kg ai/ha (2 qt/A) [oryzalin, United Phosphorus, 423 Riverview Plaza, Trenton, NJ] was made on May 19, 2003, April 21, 2004, and March 18, 2005. Finale® 1E [glufosinate-ammonium, Bayer Environmental Science, Kansas City, MO] at 1.9 g ai/liter (2 fl oz/gal) was applied for post-emergent grass control over the bark mulch on May 6 and September 4, 2003, as well as on April 21, 2004, and May 23, 2005. Trunk sprays of 0.9 g ai/liter (0.5 fl oz/gal) of Dursban® 2E, [chlorpyrifos, Dow AgroSciences LLC, Indianapolis, IN] were made on March 24 and April 27, 2004, for the control of the dogwood borer *Synanthedon scitula* (Harris).

Fungicide treatment. A randomized complete block design with six single-plant replications was used. Fungicide treatments were applied to drip with a CO_2-pressurized sprayer on a hand-held wand from April 4 to July 1, 2003; April 7 to June 30, 2004; and May 19 to June 29, 2005. While the biofungicide Rhapsody®, [*Bacillus subtilis* QST 713, AgraQuest, Davis, CA] was applied at a rate of 30 ml/liter on a 1-week schedule, Neem Concentrate [clarified extract of neem oil, Green Light® Co., San Antonio, TX] at 5.2 g ai/ha and 1% v/v of SunSpray Ultra Fine Oil® [paraffinic oil, Sonoco, Philadelphia, PA] were applied at 1- and 2-week intervals. Synthetic fungicides Immunox® Multipurpose Fungicide [myclobutanil, Spectracide Products, St. Louis MO] at 0.16 g ai/ha, Eagle® 40W at 0.24 g ai/ha [myclobutanil, Dow AgroSciences LLC, Indianapolis, IN], 0.6 g ai/ha of 3336™ 50W [thiophanate-methyl, Cleary Chemical Corp., Somerset, NJ], and 0.06 g ai/ha of ferti-loam® Liquid Systemic Fungicide® [propiconazole, Voluntary Purchasing Group, Bonham, TX] were applied at 2-week intervals.

Tree growth. Tree height and trunk diameter were recorded on February 18, 2003, January 14, 2004, January 18, 2005, and January 10, 2006. Differences in tree height and trunk diameter over time were determined by subtracting the initial height or trunk diameter measurement from the final measurement for each of those growth parameters.

Disease assessment. Incidence of spot anthracnose on the bracts and leaves, powdery mildew, and Cercospora leaf spot were visually rated using the Horsfall and Barratt rating scale where 1 = no disease, 2 = 0 to 3%, 3 = 3 to 6%, 4 = 6 to 12%, 5 = 12 to 25%, 6 = 25 to 50%, 7 = 50 to 75%, 8 = 75 to 87%, 9 = 87 to 94%, 10 = 94 to 97%, 11 = 97 to 100%, and 12 = 100% of the leaves diseased or prematurely shed. Spot anthracnose was rated on the leaves on April 23, May 19, and June 18, 2003; May 7, 2004; and April 22, May 12, and June 20, 2005. Ratings for powdery mildew were taken on May 29, June 18, and July 16, 2003; May 20, June 16, and July 8, 2004; and May 12, June 20, and July 22, 2005. Cercospora-related leaf spotting and defoliation was rated separately on August 18, October 3, and October 30, 2003; August 2, August 24, September 30, and October 27, 2004; and July 22, August 22, September 2, October 5, October 18, and November 5, 2005. In addition, the leaves of all dogwoods were periodically examined for symptoms of fungicide phytotoxicity during each year.

Significance of fungicide treatment effects on the incidence and/or severity of the diseases spot anthracnose, powdery mildew, and Cercospora leaf spot as well as on tree dimensions was tested by analysis of variance. Means were compared with Fisher's protected least significant difference (LSD) test with a level of significance of P = 0.05. Areas under the disease progress curves (AUDPC) were calculated for each treatment: $AUDPC = \Sigma_i^n [(1/2)(y_{i+1} + y_i)(t_{i+1} + t_i)]$ where y = the disease rating at time t and I = the day of the assessment from the first date of assessment. AUDPC values were used to compare season-long treatment efficacy for the control of powdery mildew and Cercospora leaf spot. Since fungicide treatment rankings differed significantly (P = 0.05) between years, disease rating data was not pooled across years.

Results and Discussion

Spot anthracnose on flower bracts. In all three years, pin head-sized brown spots with a purple halo characteristic for spot anthracnose were first noted as the bracts and juvenile leaves unfurled. Spot anthracnose damage sometimes was so severe that the bracts failed to fully unfurl. While symptoms continued to appear on juvenile leaves after showers into late June, little if any disease spread was seen during the summer.

Fungicides applied in 2003 had a significant impact on the incidence of spot anthracnose on the bracts and percentage of aborted flower buds seen the following spring. When compared with the untreated controls, all fungicide treatments except for SunSpray Ultra Fine Oil significantly reduced the incidence of spot anthracnose on the bracts in 2004 (Table 1). On the untreated controls, bract spotting and deformation was seen on more than 75% of the blooms compared with fewer than 6% of the blooms of the dogwoods treated in the previous year with Immunox, Eagle 40W, Liquid Systemic Fungicide, or 3336 50W. Synthetic fungicides were equally effective in reducing the percentage of aborted flower buds that failed to fully open (data not shown). While some reduction in percentage of aborted buds was obtained with Rhapsody and both Neem Concentrate treatments, the level of disease control was worse than that given by Immunox, Eagle 40W, Liquid Systemic Fungicide, and 3336 50W. Despite higher disease pressure in 2005, the level of spot anthracnose-associated bract abortions was greatly reduced with the synthetic fungicides (Table 1). Incidence of damaged bracts on trees treated with the above fungicides in 2005 was 7 to 12% compared with 100% for the untreated control. In contrast, disease incidence ratings for Rhapsody, Neem Concentrate, and SunSpray Ultra Fine Oil programs were very similar to the nearly 100% incidence rating for the untreated control. In 2006, Immunox, Eagle 40W, Liquid Systemic Fungicide, and 3336 50W, which limited bract spotting to less than 10% of the blossoms, gave significantly better control than the biorational fungicides (Table 1). Spot anthracnose incidence of just over 50% for the 1-week SunSpray Ultra Fine Oil and Rhapsody programs were also significantly below the 97% leaf spot incidence for the untreated control. Spot anthra-

Table 1. Incidence of spot anthracnose on the bracts and leaves of 'Rubra' flowering dogwood as influenced by applications of biorational and synthetic fungicides.

			Spot anthracnose					
	Application		Bracts[y]			Leaves[y]		
Fungicide	Rate	Interval (wk)	2004	2005	2006	2003	2004	2005
Biorational fungicides								
Neem Concentrate	5.20 g ai	1	4.7c	11.7a	8.6ab	4.8ab	1.5bc	7.5a
Neem Concentrate	5.20 g ai	2	5.0bc	12.0a	8.8ab	5.7a	2.0ab	7.5a
SunSpray Ultra Fine Oil	1% v/v	1	6.7ab	11.3a	7.2bcd	4.8ab	1.2bc	6.8a
SunSpray Ultra Fine Oil	1% v/v	2	6.7ab	12.0a	10.7ab	3.3cd	1.6bc	6.2b
Rhapsody	30 ml	1	4.7c	11.0a	7.3cd	4.0bc	1.5bc	6.0b
Synthetic fungicides								
Immunox (R)[z]	0.16 g ai	2	2.0d[x]	4.5b	4.0e	1.7e	1.0c	3.3c
Eagle 40W (C)[z]	0.24 g ai	2	2.7d	4.0b	4.5cde	2.0e	1.0c	3.0c
3336 50W	0.60 g ai	2	1.8d	4.3b	3.2e	2.2de	1.2bc	3.2c
Liquid Systemic Fungicide	0.06 g ai	2	2.4d	3.8b	4.4de	2.2de	1.0bc	2.5c
Untreated Control	—	—	8.3a	11.0a	11.3a	5.3a	2.7a	6.8a

[z](R) = retail and (C) = commercial formulation of myclobutanil.

[y]Spot anthracnose incidence, which was rated on a 1 to 12 Horsfall and Barratt rating scale, was assessed on the bracts on April 20, 2004, April 7, 2005, and April 7, 2006 and on the leaves on April 23, 2003, May 7, 2004, and May 12, 2005.

[x]Means in each column that are followed by the same letter are not significantly different according to Fisher's least significant difference (LSD) test (P = 0.05).

cnose ratings for both the Neem Concentrate and 2-week SunSpray Ultra Fine Oil programs were similar to the untreated control.

In all three years, Immunox, Eagle 40W, 3336 50W and Liquid Systemic Fungicide gave excellent residual control of spot anthracnose on the bracts (Table 1). Typically, symptoms on fungicide-treated trees were restricted at most to one or a few lesions on each bract. Bract discoloration and deformation as well as premature bract drop that characterize damaging spot anthracnose outbreaks was not seen on flowering dogwood treated with the above fungicides. Such a carryover of disease control from one year to the next is highly unusual. Trivellte and Mmbaga (19) demonstrated that fall applications of biorational and synthetic fungicides, which suppressed cleistothecia formation by *E. pulchra*, slowed powdery mildew on flowering dogwood in the following spring sufficiently to delay the first fungicide application by six weeks. Eagle 40W (17), Banner MAXX [propiconazole] (20), and 3336 50W (6), which are systemic fungicides that are translocated upwards with the transpiration stream (acropetally) and locally within a leaf, eventually accumulate at the leaf tip and margins. All of the above fungicides have curative or eradicant activity in host tissues against some plant pathogenic fungi, particularly obligate parasites like the powdery mildew fungi (17). Over the treatment period, sufficient residues of the systemic synthetic fungicides penetrated the tender shoots and developing flower buds to kill the dormant conidia or hyphae of the causal fungus *E. corni*. Inoculum responsible for the light bract spotting that was noted on the systemic fungicide-treated trees may have been come from adjacent diseased flowering dogwoods.

In contrast to the year to year carryover of spot anthracnose control on the bracts by the synthetic fungicides, the biorational fungicides SunSpray Ultra Fine Oil, Neem Concentrate, and Rhapsody, which are have contact activity only, usually did not provide disease suppression the year following their application (Table 1). When compared with the untreated control, a significant reduction in bract spotting was noted with Neem Concentrate in only 2004. Regardless of the application interval, Neem Concentrate in 2003 was not as effective as any of the synthetic fungicides in reducing the level of bract spotting. Bract spotting levels were significantly lower for the 1-week SunSpray Ultra Fine Oil programs compared with the untreated control only in 2006. In that year, the bract spot anthracnose ratings for the 1-week SunSpray Ultra Fine Oil program were similar compared with Eagle 40W and Liquid Systemic Fungicide. In 2004 and 2006, Rhapsody did reduce the incidence of spot anthracnose-incited bract damage. In 2004 but not 2006, the level of disease control given by this fungicide and Neem Concentrate was similar.

Spot anthracnose on leaves. When compared with the untreated control, incidence of the leaf spot phase of spot anthracnose was significantly reduced with the most of fungicide programs except for the Neem Concentrate and the 1-week SunSpray Ultra Fine Oil program (Table 1). Spot anthracnose damage was seen on about 4% of the trees treated with Immunox, Eagle 40W, 3336 50W and Liquid Systemic Fungicide compared with 15% of the leaves on the untreated controls. Spot anthracnose control with the synthetic fungicides was similar across all 2003 rating dates (data not shown).

For 2004, spot anthracnose damage ratings recorded were below those taken in the previous year. Symptoms were seen on only 6% of the leaves on the untreated control (Table 1). On 7 May, all treatments except for the bimonthly neem concentrate program significantly reduced the incidence of spot anthracnose compared to the untreated control.

In 2005, Immunox, Eagle 40W, 3336 50W and Liquid Systemic Fungicide gave the best control of the leaf spot phase of spot anthracnose where symptoms were noted on approximately 6% of the leaves compared with nearly 50% for the untreated controls (Table 1). Spot anthracnose leaf ratings were also significantly lower for the 2-week SunSpray Ultra Fine Oil and Rhapsody treatments than the untreated control. However, neither treatment was as effective in controlling spot anthracnose as the synthetic fungicides. While Immunox, Eagle 40W, Liquid Systemic Fungicide, and to a lesser extent 3336 50W continued to give effective spot anthracnose control through June 20, disease ratings for Neem Concentrate- and SunSpray Ultra Fine Oil-treated dogwoods were significantly higher and similar, respectively, to those recorded for the untreated controls (data not shown). Final disease rating for the Rhapsody-treated dogwood and the untreated control also were similar.

Over the study period, Immunox, Eagle 40W, 3336 50W and Liquid Systemic Fungicide, when applied according to label directions, consistently gave superior control of the leaf spot phase of spot anthracnose. The level of spot anthracnose control obtained with the retail products Immunox and Liquid Systemic Fungicide was comparable to that provided by the commercial products Eagle 40W and 3336 50W.

The biorational fungicides Neem Concentrate, SunSpray Ultra Fine Oil, and Rhapsody failed to control the leaf spot phase of spot anthracnose as effectively as the synthetic fungicides. Discounting low disease pressure in 2004, no reduction in spot anthracnose ratings was obtained with Neem Concentrate when compared with the untreated control. Surprisingly, SunSpray Ultra Fine Oil applied at 2-week intervals in 2003 and 2005 significantly reduced leaf spot levels below that of the untreated control and weekly applications of the same fungicide. Spot anthracnose ratings recorded for this fungicide program as well as those for the 3336 50W- and Liquid Systemic Fungicide-treated dogwoods were similar in 2003. When compared with the untreated control, Rhapsody reduced the incidence of spot anthracnose on the leaves in 2003 and 2005 but was less effective against this disease than the systemic fungicides.

Powdery mildew. In 2003, powdery mildew appeared between the April 23 and May 29 when the feathery white colonies of the causal fungus *E. pulchra* were seen on approximately 12% of the leaves of the untreated controls (data not shown). By June 18 and July 16, 2003, approximately 30% and nearly 50%, respectively, of the leaves of the untreated trees were colonized. In contrast, less than 2% leaf colonization was noted at all rating dates on the Immunox-, Eagle 40W-, 3336 50W- and Liquid Systemic Fungicide-treated flowering dogwoods. Efficacy of the weekly but not bimonthly Neem Concentrate and Rhapsody treatments for the control of powdery mildew was often comparable to that obtained with Immunox, Eagle 40W, 3336 50W and Liquid Systemic Fungicide (Table 2). When compared with the untreated control, SunSpray Ultra Fine Oil applied at 1- and 2-week intervals often significantly reduced powdery mildew

Table 2. Control of powdery mildew on 'Rubra' flowering dogwood with selected synthetic and biorational fungicides.

Fungicide	Application		Powdery mildew AUDPC[z]		
	Rate	Interval (wk)	2003	2004	2005
Biorational fungicides					
Neem Concentrate	5.20 g ai	1	116cde	90de	382c
Neem Concentrate	5.20 g ai	2	232b	195b	653a
SunSpray Ultra Fine Oil	1% v/v	1	184bc	85de	382c
SunSpray Ultra Fine Oil	1% v/v	2	234b	143c	538b
Rhapsody	30 ml	1	158bcd	120cd	406c
Synthetic Fungicides					
Immunox (R)[y]	0.16 g ai	2	94de[x]	72e	123e
Eagle 40W (C)[y]	0.24 g ai	2	80de	64e	110e
3336 50W	0.60 g ai	2	152bcde	81de	223d
Liquid Systemic Fungicide	0.06 g ai	2	70e	62e	101e
Untreated Control	—	—	399a	298a	681a

[z](AUDPC) = Area Under the Disease Progress Curve.

[y](R) = retail and (C) = commercial formulation of myclobutanil.

[x]Means in each column that are followed by the same letter are not significantly different according to Fisher's least significant difference (LSD) test (P = 0.05).

incidence but did not give the level of control as the synthetic fungicides.

In 2004, *E. pulchra* colonies first appeared on the leaves between the May 7 and May 20. While this disease intensified between May 20 and June 16, little if any additional powdery mildew spread was seen during the summer (data not shown). Generally, powdery mildew incidence on all rating dates was significantly higher on the untreated control than on the fungicide-treated flowering dogwoods (Table 2). On July 18, poorest disease control was provided by the 2-week Neem Concentrate program. However, less than 10% of the leaves on the 2-week Neem Concentrate-treated trees were colonized compared with more than a 25% on the untreated control. Weekly applications of Neem Concentrate and SunSpray Ultra Fine Oil controlled powdery mildew as well as the synthetic fungicides. On the synthetic fungicide-treated flowering dogwoods, *E. pulchra* colonies were found on less than 1% of the leaves

Powdery mildew pressure was higher in 2005 than in the previous two years. The percentage of *E. pulchra* colonized leaves jumped from just over 3% on May 12 to nearly 100% five weeks later (data not shown). Similar increases in disease incidence were also recorded for the 2-week Neem Concentrate and SunSpray Ultra Fine Oil programs. Powdery mildew ratings for the 2-week Neem Concentrate program were similar to the untreated control at all 2005 rating dates (data not shown). Weekly Neem Concentrate, SunSpray Ultra Fine Oil, and Rhapsody programs, which reduced powdery mildew incidence compared with the untreated control, were significantly less effective in controlling this disease than Immunox, Eagle 40W, 3336 50W and Liquid Systemic Fungicide (Table 2). In June and July, colonies of *E. pulchra* were restricted to less than 3% of the leaves compared with over 25 to 50% of the leaves on trees treated weekly with Neem Concentrate, SunSpray Ultra Fine Oil, and Rhapsody.

As was confirmed in this study, Eagle 40W and Eagle 20EW [myclobutanil] (11, 16, 22) as well as Banner MAXX [propiconazole] (11, 14, 22) gave excellent control of powdery mildew on flowering dogwood. Over three years, a low level of leaf colonization by *E. pulchra* on the Eagle 40W- and Liquid Systemic Fungicide [propiconazole]-treated dogwoods was seen, particularly under high disease pressure in 2005. As previously reported by Hagan et al. (11), 3336 4.5F was significantly less effective in controlling powdery mildew than Eagle 40W or Banner MAXX. In another recent study (14), 3336 4.5F proved as effective in controlling powdery mildew on field-grown flowering dogwood as Banner MAXX.

Activity of the biorational fungicides Neem Concentrate, SunSpray Ultra Fine Oil, and Rhapsody was better against powdery mildew than spot anthracnose. In the 2003 and 2004 when powdery mildew pressure was moderate, weekly and to a lesser extent bimonthly applications of the above fungicides noticeably reduced disease incidence. Weekly applications of Neem Concentrate and Rhapsody gave the same level of powdery mildew control in those two years as the synthetic fungicides. When applied on a 1-week schedule, SunSpray Ultra Fine Oil gave the same level of control in 2003 and 2004 as 3336 50W. Previously, Hagan (11) noted a similar level of powdery mildew control on flowering dogwood with both of the above fungicides applied on a 2-week schedule. Under heavy powdery mildew pressure in 2005, however, Neem Concentrate, SunSpray Ultra Fine Oil, and Rhapsody failed to control this disease as effectively as the synthetic fungicides. Previously, SunSpray Ultra Fine Oil applied at 2-week intervals was less effective in controlling powdery mildew as Eagle 40W applied on the same schedule (16). In addition, the 2-week Neem Concentrate and SunSpray Ultra Fine Oil programs did not control powdery mildew control as well as the same fungicides applied at 1-week intervals. A similar decline in powdery mildew control on flowering dogwood with the household soaps such Palmolive®, Ajax® and Equate® when application intervals were extended from at 1- and 2-weeks (14).

Cercospora leaf spot. While the angular, brown lesions diagnostic for Cercospora leaf spot appeared on the leaves as early as late June 2003, typically symptoms were not noticeable on the untreated trees until late July to mid-August, which was approximately four weeks after fungicide program termination. Disease intensification occurred over the next six to eight weeks until nearly all but the youngest leaves at the shoot tips displayed the characteristic lesions for Cercospora leaf spot (data not shown). Within four weeks of disease onset, noticeable premature loss of the spotted and yellowed leaves was seen on the untreated controls. By late October, untreated flowering dogwoods, which suffered more than 90% defoliation, showed little fall color.

While all fungicides significantly reduced the incidence of Cercospora leaf spot compared with the untreated control on August 19, 2003, significant differences in the level of disease suppression was seen between fungicide treatments (data not shown). Both formulations of Immunox, Eagle 40W, 3336 50W, and Liquid Systemic Fungicide limited spotting to less than 2% of the leaves compared with nearly 40% of the leaves on the untreated controls. Neem Concentrate, SunSpray Ultra Fine Oil, and Rhapsody were not as effective in suppressing disease development as synthetic fungicides.

Overall defoliation levels even on the untreated controls, which were very low on August 19, reached approximately 35% on October 3, and exceeded 80% by October 30, 2003 (data not shown). By October 30, defoliation levels on the Immunox-, Eagle 40W-, 3336 50W-, and Liquid Systemic Fungicide-treated flowering dogwoods were 12 to 15%. Defoliation ratings for both the Neem Concentrate and the 1-week SunSpray Ultra Fine Oil programs did not significantly differ from those recorded for the above synthetic fungicides. Although some reduction in defoliation was obtained with the 2-week SunSpray Ultra Fine Oil treatment, Cercospora leaf spot ratings with Rhapsody and the untreated control were similar.

While a few symptomatic leaves were observed as early as mid-June 2004, the rate of Cercospora leaf spot development on the untreated controls accelerated between July 8 and August 2 (Fig. 1A). When compared with the untreated controls, significant reductions in the Cercospora leaf spot incidence were obtained at this early date with all fungicide treatments (data not shown). The percentage of disease leaves on the untreated controls rose from nearly 20% on August 2 to 90% on September 30 compared with only 3 to 10% of the leaves on the flowering dogwoods treated with a synthetic fungicide. While some Cercospora leaf spot control was obtained with both of Neem Concentrate treatments, as well as the 2-wk SunSpray Ultra Fine Oil and Rhapsody programs, none was as effective in slowing disease spread as Eagle 40W, 3336 50W, and Liquid Systemic Fungicide. Incidence of Cercospora leaf spot on trees treated at 1-week intervals with SunSpray Ultra Fine Oil was similar to those for the Eagle 40W and Liquid Systemic Fungicide programs. While Cercospora leaf spot intensified on trees from September 30 until November 9, the best disease suppression was obtained with Immunox®, Eagle 40W, 3336 50W, and Liquid Systemic Fungicide, as well as the weekly Neem Concentrate and SunSpray Ultra Fine Oil.

Although a low level of Cercospora leaf spot-incited leaf loss was seen on the untreated controls on August 24, 2004, premature defoliation was found on September 30 where the untreated controls suffered nearly 50% leaf shed compared with approximately 3% for the Eagle 40W-, 3336 50W-, and Liquid Systemic Fungicide-treated trees (Fig. 1B). When compared to the untreated controls, the 1-week Neem Concentrate and SunSpray Ultra Fine Oil programs also significantly reduced the level of Cercospora leaf spot-related defoliation. While the untreated control had lost over 90% of

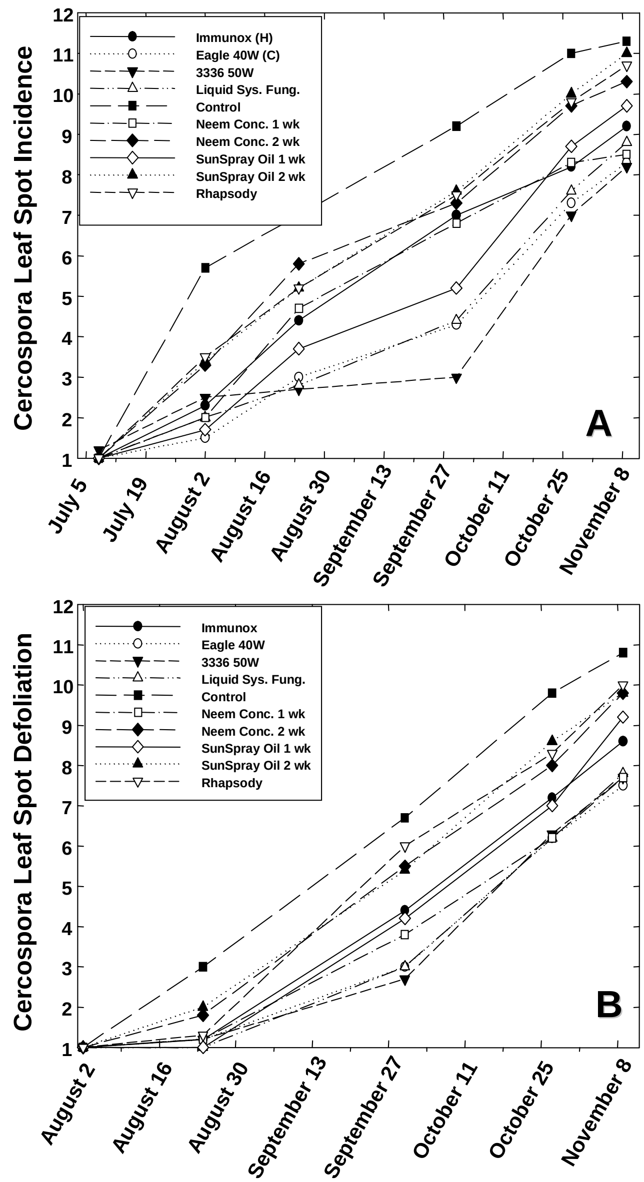

Fig. 1. Impact of fungicides on Cercospora leaf spot incidence (A) and associated premature defoliation (B) on 'Rubra' flowering dogwood in 2004.

its leaf canopy by October 27, the Eagle 40W-, 3336 50W-, and Liquid Systemic Fungicide-treated trees suffered just over 25% leaf loss and showed good fall color. In addition, the 1-week Neem Concentrate program was as effective as the latter synthetic fungicides in slowing Cercospora leaf spot-induced defoliation (data not shown). When compared with the untreated controls, the rate of premature defoliation was slowed significantly with the retail product Immunox, 1-week SunSpray Ultra Fine Oil, 2-week Neem Concentrate, and Rhapsody programs.

In 2005, Cercospora leaf spot appeared between June 20 and July 22 (Fig. 2A). By September 2, leaf spotting intensified on the untreated controls until nearly 90% of the leaves were damaged compared with 3% for the synthetic fungicide-treated trees. Immunox, Eagle 40W, 3336 50W, and Liquid Systemic Fungicide proved significantly more effective in slowing disease development than the biorational fungicides (data not shown). When compared with the untreated control, Cercospora leaf spot development was also significantly lower on trees treated with Neem Concentrate and SunSpray Ultra Fine Oil at 1- than 2-week intervals. By October 5, the Cercospora leaf spot suppression given by Eagle 40W, 3336 50W, and Liquid Systemic Fungicide declined. The percentage of symptomatic leaves was approximately 12% for Liquid Systemic Fungicide to nearly 40% for Eagle 40W compared with about 3% for these same fungicide programs in the previous month. In addition, Cercospora leaf spot ratings for the retail product Immunox, Neem Concentrate, SunSpray Ultra Fine Oil, and Rhapsody-treated dogwoods were also significantly below the untreated controls. On November 5, the percentage of disease leaves on the untreated control reached 95% compared with less than 50% for Liquid Systemic Fungicide to about 65% for 3336 50W and Eagle 40W.

On September 2, 2005, premature defoliation was noted on the untreated controls as well as on trees treated at 2-week intervals with Neem Concentrate and SunSpray Ultra Fine Oil (Fig. 2B). While defoliation levels on the above date were lower for the 1-week Neem Concentrate and SunSpray Ultra Fine Oil programs compared with the same fungicides applied on a 2-week schedule, defoliation ratings recorded for above biorational fungicides were similar on October 5 (data not shown). In contrast, the Liquid Systemic Fungicide-treated flowering dogwoods suffered less than 3% premature defoliation compared with approximately 90% for the untreated controls. At the final three rating dates, all of the fungicide-treated dogwoods had significantly lower defoliation ratings than the untreated controls. Over the same rating period, Rhapsody and the 1-week Neem Concentrate treatments were nearly as effective in slowing premature defoliation as Immunox, Eagle 40W, and 3336 50W. Overall, Liquid Systemic Fungicide slowed Cercospora leaf spot-incited premature defoliation better than all of the other fungicide treatments except for 3336 40W and Eagle 40W.

Although this study was designed to compare the efficacy of selected synthetic and biorational fungicides for the control of spot anthracnose and powdery mildew on flowering dogwood, most treatments also had sufficient residual activity to slow the spread of Cercospora leaf spot. While the fungicide programs were terminated around July 1, their impact on this disease was seen into late October or early November. The most dramatic reductions in the leaf spot and defoliation levels as well as the best fall color display were consistently obtained with the commercial products Eagle 40W and 3336 50W as well as the retail product Liquid Systemic Fungicide. While Immunox slowed the disease development compared with the untreated controls and some biorational fungicide treatments; heavier leaf spotting and premature defoliation was recorded for this treatment than Eagle 40W, which is the commercial formulation of the same fungicide. Poorer Cercospora leaf spot suppression that was obtained with Immunox than Eagle 40W is most likely due to the higher application rate for the latter treatment and not due to differences in product formulation.

While the biorational fungicides Neem Concentrate, SunSpray Ultra Fine Oil, and Rhapsody slowed the development of Cercospora leaf spot when compared with the untreated controls, none proved as efficacious in controlling this disease as Eagle 40W, 3336 50W, and Liquid Systemic Fungicide. However, leaf spotting and defoliation levels recorded for the 1-week Neem Concentrate and SunSpray Ultra Fine Oil programs were similar to those obtained with Immunox. Better season-long control of Cercospora leaf spot was obtained with Neem Concentrate and SunSpray Ultra Fine Oil applied on a 1- than 2-week schedule. Overall, the 1-week Neem Concentrate, SunSpray Ultra Fine Oil, and Rhapsody treatments generally gave a similar level of control of Cercospora leaf spot on flowering dogwood. Efficacy of the biorational fungicides for the control of Cercospora leaf spot would have been much better if the applications had continued into August or September.

Phytotoxicity. Among the fungicides screened, only SunSpray Ultra Fine Oil was phytotoxic to flowering dogwood. In all three years, a mosaic of yellow and green areas as well as interveinal chlorosis along the larger veins was

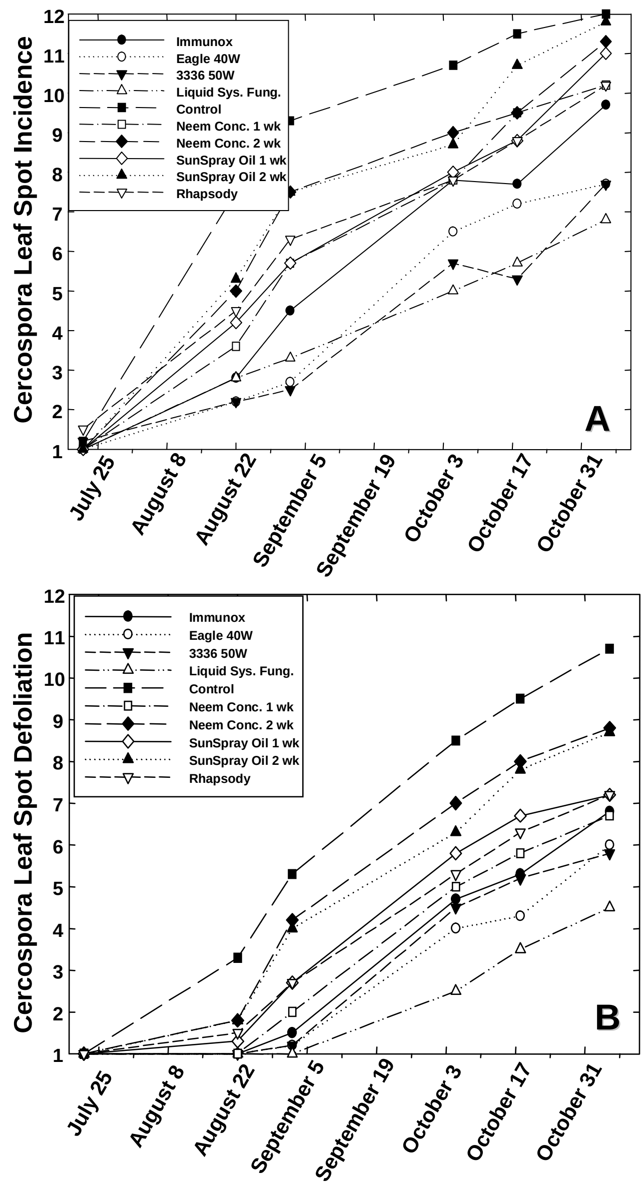

Fig. 2. Impact of fungicides on Cercospora leaf spot incidence (A) and associated premature defoliation (B) on 'Rubra' flowering dogwood in 2005.

consistently seen on the leaves of the SunSpray Ultra Fine Oil-treated flowering dogwoods. Typically, these symptoms were more noticeable, particularly during the summer months, on the trees treated with SunSpray Ultra Fine Oil at 1- than 2-week intervals. These symptoms did not progress to a marginal leaf burn or accelerate the rate of premature defoliation. In recent studies, SunSpray Ultra Fine Oil did not damage the leaves of flowering dogwood grown on full-sun (16) or under 47% shade cloth (11). SunSpray Ultra Fine Oil-induced leaf spotting or chlorosis has been noted on other container-grown woody ornamentals (12). While differences in flowering dogwood cultivar sensitivity to paraffinic oil may be responsible for the variation in phytotoxicity noted between studies, applications of this pesticide to juvenile leaves on trees in full sun in May or June when mid-day temperatures often exceeded 32C (90F) is the most likely explanation for the damage observed.

Tree dimensions. Superior disease control obtained with some fungicides did not translate into increased tree height or trunk diameter when compared with the untreated control (data not shown). Tree growth as measured by the difference in initial and final tree height was similar for the untreated and fungicide-treated flowering dogwoods. However, the Liquid Systemic Fungicide-treated flowering dogwoods were shorter than those treated with Immunox, Neem Concentrate, or SunSpray Ultra Fine Oil at 2-week intervals. Trunk diameter was higher for the flowering dogwoods treated with Immunox than with Liquid Systemic Fungicide, Eagle 40W, weekly Neem Concentrate treatment, and the untreated controls.

Plant growth regulator (PGR) activity associated with the extended use of triazole (ergosterol biosynthesis inhibiting) class fungicides like Immunox, Eagle 40W, and Liquid Systemic Fungicide be partially responsible for some of the differences in tree height (17, 20). However, Hagan et al. (11) recently noted that the canopy dimensions (height and width) and trunk diameter of container-grown flowering dogwoods treated with Eagle 40W and Banner MAXX exceeded those of the untreated controls. Mmbaga and Sauve (14) also saw the largest increases in trunk diameter on Banner MAXX-treated flowering dogwoods. On container-grown flowering dogwood, fungicides may be more likely to increase tree growth when damaging outbreaks of powdery mildew are controlled.

In summary, synthetic fungicides Liquid Systemic Fungicide, 3336 50W, Immunox and Eagle 40W usually gave superior control of spot anthracnose, Cercospora leaf spot, and to a lesser extent powdery mildew than the biorational fungicides Neem Concentrate, Rhapsody, and SunSpray Ultra Fine Oil. In addition, Neem Concentrate and SunSpray Ultra Fine Oil had to be applied at 1-week intervals to obtain powdery mildew control comparable to the level provided by synthetic fungicides, which were applied on a 2-week schedule. Efficacy of the biorational fungicides for the control of powdery mildew declined sharply when disease pressure was high. Due to the risk of significant leaf damage, SunSpray Ultra Fine Oil should not be applied in to flowering dogwood growing in full sun.

Among the synthetic fungicides, the most effective overall disease control was obtained with the commercial product Eagle 40W and the retail product Liquid Systemic Fungicide, which can be purchased at garden centers and other retail outlets. Banner MAXX is the formulation of propiconazole available to the commercial landscape, greenhouse, and nursery industry. While 3336 50W controlled spot anthracnose and Cercospora leaf spot as well as Immunox, Eagle 40W, and Liquid Systemic Fungicide, the former fungicide proved slightly less efficacious in controlling powdery mildew. Halt [Voluntary Purchasing Group (fertiloam®), Bonham TX], which contains the same active ingredient as 3336™ 50W, is also sold at garden centers. The level of powdery mildew and spot anthracnose control obtained with Eagle 40W and Immunox, which are retail and commercial formulations of myclobutanil, respectively, was similar. Immunox did not slow the development of Cercospora leaf spot as effectively as commercial formulation of the same fungicide. Poorer control of Cercospora leaf spot with Immunox and Eagle 40W probably can be attributed an application rate of 0.16 g ai/liter compared with the 0.24 g ai/liter for the retail and commercial formulations, respectively, of this same fungicide.

Exclusive use of the benzimidiazole fungicide 3336 50W as well as triazole fungicides Immunox, Eagle 40W, and Liquid Systemic Fungicide over an extended period of time can result in control failures due to resistance in target plant pathogenic fungi. Such control failures are far more likely to occur in a nursery production than landscape setting, particularly with 3336 50W and other benzimidiazole fungicides (6). According to FRAC [Fungicide Resistance Action Committee, www.frac.info/frac/index.htm] guidelines, the risk of a control failure due to resistance can be minimized by restricting the use of at-risk benzimidiazole or triazole fungicides to no more than ½ of the total number of fungicide applications made to a given crop per production cycle or growing season. While alternating a benzimidiazole and triazole fungicide is acceptable, rotating or tank-mixing a synthetic or possibly biorational fungicide with a benzimidiazole and/or triazole fungicide is the preferred method of reducing the risk of a control failure due to tolerance or resistance in target plant pathogenic fungi.

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