Chlorothalonil Fungicides Reduce Vase Life but not Yield of Leatherleaf Fern [*Rumohra adiantiformis* (Forst.) Ching]

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Abstract. Established ground beds of leatherleaf fern were sprayed repeatedly with water, a flowable formulation of thiophanate-methyl, or one of four formulations of chlorothalonil on a predominantly weekly schedule. None of the treatments produced visible phytotoxicity symptoms or had any effect on yield (frond number and total fresh mass). However, average masses of fronds from plots treated with a liquid formulation of chlorothalonil were 21% greater than those from control plots. All chlorothalonil formulations left visible residues on the fronds and reduced frond vase life compared to fronds treated with water or thiophanate-methyl. Reduced vase life was due to more rapid desiccation of chlorothalonil-treated fronds. During those months (July–Sept.) when postharvest desiccation is most common, chlorothalonil reduced vase life of fronds by 36% to 62%. Vase life of fronds was generally reduced more by dry chlorothalonil formulations than by liquid ones, probably due to slightly higher application rates of dry formulations. Determination of the mode of action could lead to an understanding of the causes of frond curl syndrome. Until a remedy is found, chlorothalonil should not be used repeatedly on leatherleaf fern. Chemical names used: tetrachlorisophthalonitrile (chlorothalonil); dimethyl [(1,2-phenylene)-bis(iminocarbonothioyl)]bis(carbamate) (thiophanate-methyl).

Leatherleaf fern accounts for over 56% of the wholesale value of cut cultivated greens production in the United States and is valued at over \$66 million (U.S. Dept. of Agriculture, 1997). Large, dark-green, blemish- and residue-free fronds are preferred by florists. This true fern is grown under shade in tropical and subtropical areas that generally have significant rainy seasons. During those wet periods, foliar fungal diseases can cause significant damage to the crop. The primary fungal pathogens include members of the genera *Colletotrichum*, *Cylindrocylindrium*, and *Rhizoctonia* (Stamps, 1992a; Stamps et al., 1994). Anthracnose of leatherleaf fern, caused by *Colletotrichum acutatum* and first identified in the United States in 1993, is impossible to control without intensive fungicide spray programs (Leahy et al., 1995). In the United States, chlorothalonil and thiophanate-methyl are the only fungicides labeled for controlling all three primary diseases of this crop (Stamps et al., 1995). Consequently, both fungicides are widely used during periods of disease occurrence.

These rainy seasons also coincide with those times of the year when fronds develop that have shorter postharvest life due to rapid water loss (Mathur et al., 1982; Poole et al., 1984), a phenomenon known as frond curl syndrome (Nell et al., 1983). Higher ambient temperatures during frond development reduce vase life of mature fronds by increasing postharvest desiccation (Stamps et al., 1989). Pesticide use may also contribute to reduced postharvest longevity. Yield and postharvest effects of pesticides applied to leatherleaf fern during production have been determined only for certain herbicides (Stamps, 1992b; Stamps and Poole, 1982, 1987).

The primary purpose of this experiment was to determine if repeated applications of chlorothalonil and thiophanate-methyl fungicides affected yield and postharvest longevity of leatherleaf fern fronds. Therefore, the fern was not inoculated with fungal pathogens because doing so would cause damage in the control plots and make comparison of un-

treated fronds with fronds treated with the fungicides impossible. A secondary objective was to compare the residues left on the foliage by the fungicide treatments.

Materials and Methods

The experiment was conducted in an established fernery in Apopka, Fla., where the soil was Tavares-Millhopper fine sand [hyperthermic; uncoated Typic Quartzipsamments (Tavares), Grossarenic Paleudults (Millhopper)]. The fernery was covered with polypropylene fabric designed to exclude 70% of radiation when the radiation source is perpendicular to the plane of the fabric. Irrigation water was supplied to the 1.2 × 4-m plots as needed using a solid set overhead irrigation system. Nutrients were supplied using an 18N–2.6P–6.6K controlled-release fertilizer (Nutricote Total Type 180; PlantCo, Brampton, Canada) applied twice a year at a rate of 334 kg N·ha⁻¹·yr⁻¹, starting 28 Dec. 1993. Leatherleaf fern anthracnose was not present in this fernery.

All harvestable fronds were removed from plots prior to beginning the experiment, which was a completely randomized block design with six replications. Treatments consisted of spray applications of labeled concentrations (Table 1) of four formulations of chlorothalonil (Daconil 2787 F and Ultrex WDG; ISK Biosciences, Mentor, Ohio; Thalonil 90DF and 4L, Terra International, Sioux City, Iowa), one formulation of thiophanate-methyl (3336 F; W.A. Cleary Chemical, Somerset, N.J.) and a water control. Spray solutions were thoroughly mixed in 2-L bottles prior to application. All treatments were applied with initial and final system pressures of ≈400 and 150 kPa, respectively, and with enough volume for thorough foliar coverage (1.25 L per plot; 2587 L·ha⁻¹ equivalent). Sprays were applied using an air-pressurized sprayer with an 80° flat-fan nozzle. Treatments were applied weekly 13 June and continuing through 29 Aug. 1994. From 13 Sept. to 13 Oct. 1994, application rates were lowered and treatment intervals extended to once every 2 weeks to simulate chemigation rates used in the industry prior to the introduction of leatherleaf fern anthracnose (Table 1). In late September and early October, all plots were treated with insecticides to control caterpillars.

Phytotoxicity and amount of fungicide residue on fronds were rated about every 30 d

Table 1. Fungicide spray concentrations used and equivalent active ingredient rates applied to leatherleaf fern, 1994.

Chemical	Formulation (a.i.)	Concn	Application	Concn	Application
		(amt. of product per L of water)	rate (kg a.i./ha)	(amt. of product per L of water)	rate (kg a.i./ha)
		13 July–29 Aug. ²		13 Sept.–13 Oct. ³	
Water control	---	---	---	---	---
Thiophanate-methyl	0.54 kg·L ⁻¹ F	1.6 mL	2.1	0.58 mL	0.79
Chlorothalonil	0.5 kg·L ⁻¹ F	2.6 mL	3.2	0.9 mL	1.11
Chlorothalonil	0.82 kg·kg ⁻¹ WDG	1.7 g	3.6	0.55 g	1.23
Chlorothalonil	0.9 kg·kg ⁻¹ DF	1.5 g	3.5	0.55 g	1.23
Chlorothalonil	0.5 kg·L ⁻¹ L	2.6 mL	3.2	0.9 mL	1.11

²Applied weekly for thorough foliar coverage using labeled concentrations for control of anthracnose.

³Applied biweekly at pre-leatherleaf fern anthracnose rates.

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beginning 15 July 1994. Ratings were made on the fronds in a 0.9×3.4 -m center area of each plot, thereby providing a 0.6-m buffer between plots. Phytotoxicity ratings were 0 = none; 1 = slight, fronds salable; 2 = moderate damage, some fronds unsalable; 3 = severe damage, fronds unsalable; 4 = dead. Visual residue ratings were 0 = none; 1 = slight; 2 = moderate, objectionable but salable; 3 = severe, unsalable without treatment to mask residues.

Vase life was evaluated five times at ≈ 30 -d intervals beginning 18 July 1994. For vase life studies, 10 stems were cut from each plot, weighed, and immersed in tap water for 30 min. Excess water was allowed to drain from the fronds, the groups of wet fronds from each plot were placed in individual polyethylene bags, and the bags were placed in wax-coated, corrugated fiberboard boxes. The boxes were stored in a cooler maintained at 4°C for 2 to 3 weeks. Upon removal from the cooler, all fronds were freshly cut to a stipe length of 15 cm from the first pinna and placed in 2-L beakers filled with deionized water. These studies were conducted in a room maintained at $24 \pm 2^\circ\text{C}$, $64 \pm 11\%$ RH and light levels of $17 \mu\text{mol}\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ provided 12 h a day using cool-white fluorescent lamps (simulated home/office conditions). Fronds were discarded when signs of desiccation or chlorosis appeared.

Yields were determined by harvesting all commercially acceptable fronds on 7 Dec. 1994 and adding those frond numbers and fresh masses to the ones previously determined from the five vase life harvests.

Vase life and yield data were analyzed by analysis of variance, using Duncan's new multiple range test at $P \leq 0.05$ for mean separation (SAS, SAS Inst., Cary, N.C.). Ratings were analyzed using chi-square.

Results and Discussion

Phytotoxicity. The very limited phytotoxicity observed was not treatment related (data not shown).

Foliar fungicide residues. Objectionable residues were apparent on mature fronds in all chlorothalonil-treated plots after a month of weekly applications (Fig. 1). This was expected, as the manufacturers of these products use formulations that resist washoff from rainfall and irrigation. Plots treated with the dry (DF and WDG) formulations tended to have slightly higher residues than those treated with the liquid (F and L) formulations, probably due to the higher labeled application rates for the dry vs. the liquid formulations (Table 1). Residues remained high in October despite the reduced spraying regimen. This was because insecticides applied to all the plots for caterpillar control left additional residues, as evidenced by the presence of residues in the control and thiophanate-methyl plots.

Vase life. Thiophanate-methyl-treated fronds lasted as long as water-treated fronds in all evaluations (Fig. 2), whereas chlorothalonil-treated fronds had shorter vase life than the controls at all harvests except for the F formulation in July and the L formulation in October.

Reductions during August, September, and October—months when postharvest desiccation is greatest (Poole et al., 1984)—ranged from 36% to 62%. These reductions were due to more rapid loss of frond water balance as evidenced by earlier and more pronounced desiccation for chlorothalonil-treated fronds. For example, 92% of chlorothalonil-treated vs. 15% control fronds were terminated due to desiccation in the first week at the September evaluation. Even after the application rates were reduced and intervals extended, three of

the four chlorothalonil treatments reduced vase life (November harvest). This is the first report of reduced postharvest longevity caused by pesticide application during the production of this crop.

When averaged across the five harvests, vase life for the treatments segregated into three groups—control and thiophanate-methyl > the liquid chlorothalonil formulations > the dry chlorothalonil formulations. Differences in the degree of reduction by the chlorothalonil formulations were probably related,

Fig. 1. Visual pesticide residue ratings on leatherleaf fern fronds treated weekly or biweekly with fungicides (0 = none; 1 = slight; 2 = moderate, objectionable but salable; 3 = severe, unsalable without treatment). Residue ratings were generally higher for the dry (WDG, DF) than for the liquid (F, L) formulations of chlorothalonil (chi-square $P \leq 0.001$).

Fig. 2. Vase life of leatherleaf fern fronds held in deionized water following storage for 2 or 3 weeks at 4°C . Mean separation within months, using Duncan's new multiple range test at $P \leq 0.05$.

as in the case of residues, simply to differences in labeled application rates. Further research is needed to determine if the reduction of vase life is due to reduced water uptake, impaired stomatal closure, and/or effects on cuticle development/integrity.

Yield. Despite the deleterious postharvest effects of chlorothalonil, fungicide treatments did not affect yield (frond number and total fresh mass) (Table 2). Fronds from chlorothalonil L-treated plots were heavier than those from control plots and more harvestable fronds were produced in chlorothalonil WDG-treated than in chlorothalonil L-treated plots. Previous work has shown that leatherleaf fern frond mass and size are positively correlated (Stamps and Mathur, 1982). Since certain markets demand and pay more for large fronds, a factor that increases frond size would be of interest to the industry. Additional testing is needed to confirm these preliminary results. Note that no foliar fungal disease developed in any of the plots during this experiment. If any had developed, yield from the control plots probably would have been reduced compared to the fungicide-treated plots.

Although repeated applications of chlorothalonil fungicides to leatherleaf fern were not phytotoxic from a gross morphological standpoint and had relatively little effect on frond yield, they did create objectionable foliar residues and greatly reduce vase life. The cause of the accelerated postharvest desiccation of chlorothalonil-treated fronds is not known and may be due to any of a number of factors affecting water movement into and out of the fronds. Until the causes are understood and methods to offset them are developed, chlorothalonil fungicides should not be used repeatedly and/or at high application rates on leatherleaf fern.

Table 2. Effects of fungicide treatments on leatherleaf fern frond yield.

Treatment	Formulation (a.i.)	Total frond		Avg frond fresh mass (g)
		No.	Fresh mass (kg)	
Water control	---	528 ab ^a	7.0 a	13.3 b
Thiophanate-methyl	0.54 kg·L ⁻¹ F	485 ab	6.8 a	14.2 ab
Chlorothalonil	0.5 kg·L ⁻¹ F	510 ab	6.9 a	13.6 ab
Chlorothalonil	0.82 kg·kg ⁻¹ WDG	539 a	7.9 a	14.8 ab
Chlorothalonil	0.9 kg·kg ⁻¹ DF	501 ab	7.4 a	14.9 ab
Chlorothalonil	0.5 kg·L ⁻¹ L	424 b	6.6 a	16.1 a

^aMean separation in columns by Duncan's multiple range test, $P \leq 0.05$.

erleaf fern. Determination of how chlorothalonil is affecting leatherleaf fern fronds could possibly lead to a cure for frond curl syndrome.

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