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Nursery Crops Research at the North Willamette Research and Extension Center (NWREC)

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Nursery Crops Research at the North Willamette Research and Extension Center (NWREC)

Introduction

Beginning with Dr. Robert L. Ticknor (retired) in the late 1950s, nursery crops research has been an important activity at the North Willamette Research and Extension Center. The Center, a branch of both Oregon State University's Agricultural Experiment Station and its Extension Service, is just north of Aurora, a historic farming community 20 miles south of Portland, Oregon. The Center serves the nursery, wine grape, small fruit and vegetable crops industries and is located in an area noted for the diversity of its agriculture. Our nursery crops research emphasizes the needs of the nursery crops growers of Oregon's Willamette Valley and of the Pacific Northwest region of the United States. We also conduct research on landscape plant culture and use.

Many of the research projects reported here involved cooperation with Experiment Station and Extension Service colleagues at Oregon State University. Their contributions are gratefully acknowledged. The financial support of the Oregon Department of Agriculture Nursery Research Program and the Oregon Association of Nurserymen was essential to completing these projects and is greatly appreciated.

Insecticide Efficacy for Adult Root Weevil Control

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North Willamette Research and Extension Center
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Introduction

Sometimes called the "Trojan horse" of the nursery industry (Cowles et al., 1997), root weevil species are pests in nurseries world-wide (Bogatko and Labanowski, 1993; Horne, 1997). In a recent survey of *Rhododendron* growers in Oregon, 54% of respondents were not satisfied with the level of root weevil control when pesticides were used (Rosetta and Svenson, unpublished data). This dissatisfaction persisted even when there were no out-of-state *Rhododendron* shipments rejected due to root weevil infestations (Reusche, 1999). The objective of this study was to determine the efficacy of selected pesticides for control of adult root weevils.

Methods

The study was conducted on *Rhododendron* 'PJM' in 1-gallon (2.7-liter) containers at the North Willamette Research and Extension Center in July of 1999. Adult stages of black vine root weevil (*Otiorhynchus sulcatus*), strawberry root weevil (*Otiorhynchus ovatus*), and rough strawberry root weevil (*Otiorhynchus rugostriatus*) were established in each pot. Pesticide applications were made on 12 July 1999. Insecticides studied included: bifenthrin (Talstar flowable); lambda cyhalothrin (Topcide); deltamethrin (Alta); bendiocarb (Closure); and acephate (Orthene). Treatments were evaluated for percent adult mortality and effective kill ratio (EKR) at 7 and 14 DAT (July 19 and July 26, respectively). The EKR adjusts the data for natural mortality, based on the percent of dead weevils in untreated controls. The randomized complete block experiment used five blocks with two pots for each treatment. Data were checked for normality and homogeneity, and then analysis proceeded with SAS ANOVA using the LSD procedure for mean comparisons.

Results

Data is summarized in Tables 1-3. The results were significant by treatment and weevil species on 7 DAT. There was a significant treatment by species interaction 7 DAT. The results were significant by treatment and weevil species on 14 DAT. There was no treatment by species interaction 14 DAT.

Compared to other pesticides, only bendiocarb did not kill a higher fraction of strawberry root weevil after 7 days (Table 1). However, when adjusted for natural mortality in the control, then both bendiocarb and acephate did not have an EKR for strawberry root weevil signicantly different from the untreated control. Lambda cyhalothrin and bifenthrin had a significantly higher fraction of dead strawberry root weevil after 14 days, but only lambda cyhalothrin had an EKR different from the untreated control after 14 days.

Compared to untreated controls, only deltamethrin and bifenthrin had a higher fraction of dead black vine root weevils after 7 days (Table 2). This difference in weevil species response to applied pesticides compared to strawberry root weevil partly explains the significant treatment by species interaction for 7 DAT. When adjusted for natural mortality in the control, both deltamethrin and bifenthrin had an EKR for black vine root weevil signicantly different from the untreated control. Failure of lambda cyhalothrin to have an EKR significantly different from the untreated plant 7 DAT for black vine root weevil compared to strawberry root weevil also helps explain the significant treatment by species interaction for 7 DAT. Fourteen days after treatment, none of the applied pesticides had a fraction dead or an EKR significantly higher than the untreated controls for black vine root weevil, but all of the treated black vine weevils were dead compared to only 60 percent of untreated controls.

Compared to untreated controls, only lambda cyhalothrin had a higher fraction of dead rough strawberry root weevils after 7 days (Table 3). This difference in weevil species response to applied pesticides compared to other root weevil species partly explains the significant treatment by species interaction for 7 DAT. When adjusted for natural mortality in the control, all pesticides except bifenthrin had an EKR for rough strawberry root weevil signicantly higher than the untreated control. Failure of bifenthrin to have an EKR significantly different from the untreated control 7 DAT for rough strawberry root weevil compared to other root weevil species also helps explain the significant treatment by species interaction for 7 DAT. Fourteen days after treatment, none of the applied pesticides had a fraction dead or an EKR significantly higher than the untreated controls for rough strawberry root weevil.

Black vine weevils were considerably more sensitive to the insecticides studied than either strawberry root weevil or rough strawberry root weevil. After 14 days, only black vine root weevil had 100 percent kill for all applied pesticides, but the high percent of natural death (60 percent) may have contributed to the efficacy of the pesticides. Black vine root weevil and strawberry root weevil are both common in nursery stock in the Pacific Northwest, but infestations by rough strawberry root weevils are less common.

As there was considerable mortality of the black vine root weevils (60 percent) and rough strawberry root weevils (77 percent) in the untreated plots by 14 DAT, it may be more useful to look at the results from 7 DAT for pesticide comparisons. Mortality of the strawberry root weevils in the untreated plots by 14 DAT remained relatively low, and both evaluation dates should be useful.

The efficacay of acephate and bifenthrin against black vine root weevil in this study is similar to the results from our previous studies completed in 1997 and 1998 (data not shown).

To our knowledge, this is the first study showing different responses to pesticides among root weevil species. The efficacy of a pesticide on a particular root weevil species should not be applied to another root weevil species. Similarly, the efficacy of a pesticide used for root weevil control on a particular plant species or clone of *Rhododendron* should not be applied to other plant species or other *Rhododendron* clones without careful study.

In this study, potted plants were surface-irrigated by hand as needed, and were not exposed to natural rainfall. Results may be different if plants were placed under overhead irrigation, if plants were exposed to natural rainfall, or if other conditions exist that may wash pesticide residuals off of plant surfaces.

Literature cited

Bogatko, W. and G. Labanowski. 1993. Chemical control of the black vine weevil (*Otiorhynchus sulcatus* F.) on ornamental crops. J. Fruit and Orn. Plant Res. 1(3):93-101.

Cowles, R.S., D.O. Gilrein. and S.R. Alm. 1997. The Trojan horse of the nursery industry. Amer. Nurs.186(3):51-57.

Horne, P.A. 1997. Grubs in your pots? Are they weevils and what can you do about it? The Nursery Papers 11:1-7.

Reusche, E. 1999. Summary of rejections of Oregon nursery stock in 1999. Nursery News 1(4):3.

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The authors thank Neil Bell, Thirza Collins, Alison Henderson, Beth Mills, Kathy Sanford, Claudia Belville, Bradon Ramage, and Andrew Billette for technical assistance with this research, and thank our nursery cooperators and the Oregon Department of Agriculture's Nursery inspectors for their help with this project.

Table 1. Influence of insecticides on mortality of strawberry root weevil in *Rhododendron* 'PJM.'

Insecticide	Application rate	Fraction Dead[2]		EKR[3]	
		7 DAT	14 DAT	7 DAT	14 DAT
Lambda cyhalothrin	0.48 oz ai/100 gal	90 ab[1]	90 a	88 ab	87 a
Bifenthrin	0.19 oz ai/100 gal	60 bc	76 ab	54 abc	68 ab
Deltamethrin	0.19 oz ai/100 gal	58 bc	68 abc	52 abc	67 ab
Acephate	12.0 oz ai/100 gal	54 bc	65 abcd	47 bcd	53 abc
Bendiocarb	6.08 oz ai/100 gal	25 cde	60 abcd	21 cde	47 abc
Untreated control	0	13 de	25 cde	0 de	0 bc

[1] Means in columns for the same days after treatment and followed by the same letter are not significantly different; mean separation using LSD (5%).
[2] Fraction of dead weevils from mean all weevils found per treatment (DAT=days after treatment).
[3] Effective Kill Ratio; values may be lower on 14 DAT compared to 7 DAT due to sampling errors or missing weevils.

Table 2. Influence of insecticides on mortality of black vine weevil in *Rhododendron* 'PJM.'

Insecticide	Application rate	Fraction Dead[2] 7 DAT	Fraction Dead[2] 14 DAT	EKR[3] 7 DAT	EKR[3] 14 DAT
Lambda cyhalothrin	0.48 oz ai/100 gal	75 ab[1]	100 a	63 abc	100 a
Acephate	12.0 oz ai/100 gal	80 ab	100 a	70 ab	100 a
Bifenthrin	0.19 oz ai/100 gal	100 a	100 a	100 a	100 a
Deltamethrin	0.19 oz ai/100 gal	100 a	100 a	100 a	100 a
Bendiocarb	6.08 oz ai/100 gal	75 ab	100 a	3 abc	100 a
Untreated control	0	33 bc	60 ab	0 bc	0 ab

[1] Means in columns for the same days after treatment and followed by the same letter are not significantly different; mean separation using LSD (5%).
[2] Fraction of dead weevils from mean all weevils found per treatment (DAT=days after treatment).
[3] Effective Kill Ratio; values may be lower on 14 DAT compared to 7 DAT due to sampling errors or missing weevils.

Table 3. Influence of insecticides on mortality of rough strawberry root weevil in *Rhododendron* 'PJM.'

Insecticide	Application rate	Fraction Dead[2] 7 DAT	Fraction Dead[2] 14 DAT	EKR[3] 7 DAT	EKR[3] 14 DAT
Acephate	12.0 oz ai/100 gal	80 ab[1]	100 a	100 a	100 a
Lambda cyhalothrin	0.48 oz ai/100 gal	93 a	100 a	100 a	100 a
Bendiocarb	6.08 oz ai/100 gal	71 abc	93 ab	70 a	71 ab
Untreated control	0	44 bcde	77 abc	0 b	0 abc
Bifenthrin	0.19 oz ai/100 gal	33 cdef	75 abc	0 bc	0 abc
Deltamethrin	0.19 oz ai/100 gal	56 bcd	67 abc	100 a	5 abc

[1] Means in columns for the same days after treatment and followed by the same letter are not significantly different; mean separation using LSD (5%).
[2] Fraction of dead weevils from mean all weevils found per treatment (DAT=days after treatment).
[3] Effective Kill Ratio; values may be lower on 14 DATcompared to 7 DAT due to sampling errors or missing weevils.

Azalea Container Production Using 18-Month Controlled-Release Fertilizers

Introduction

To help reduce the possibility of environmental pollution from fertilizer runoff, and to help reduce labor costs, Oregon nurseries often fertilize container grown crops with controlled-release fertilizers.

Many container nursery crops grown in Oregon are on 18- or 24-month production cycles. Since most controlled-release fertilizers are formulated to last less than 18 months, plants require a second application of controlled-release fertilizers. Longer-lasting controlled-release fertilizers are needed to eliminate the expensive labor required by the second fertilizer application. Two experimental 18-month controlled-release fertilizers were compared to a typical fertilization regime to determine if a single application of controlled-release fertilizer, incorporated into the growing substrate before potting, could substitute for split-applications of a market-available controlled-release fertilizer.

Methods

On 25 September 1997, *Rhododendron* 'Getsutoku' were potted into trade 1-gal black poly containers filled with 100 percent Douglas-fir bark. Before potting, substrates were amended with either Osmocote 16-8-12 (Scotts), a 15:20:20:45 (by weight) blend of Nutricote 16-10-10 types 70:100:180:270 (Agrivert), or with Apex 20-10-10 (Purcell). Osmocote 16-8-12 was incorporated at 2.4 lb N/yd^3, with a second top-dress application at the same rate applied on 3 June 1999 accumulating to a total of 4.75 lb N/yd^3 for the duration of the crop. Nutricote 16-10-10 was incorporated at 2.4, 3.2 or 4.0 lb N/yd^3. Apex was incorporated at 2.75, 3.75, or 4.75 lb N/yd^3. The 7 fertilizer treatments were arranged in a randomized complete block design with 12 blocks in an uncovered 17 x 96-ft hoop structure at the North Willamette Research and Extension Center (45 degrees 17 minutes north by 122 degrees 45 minutes west; 150 feet above sea-level). Weather records for this site can be viewed on the AgriMet internet site at http://mac1.pn.usbr.gov/agrimet/ (select Aurora, OR). The hoop structure was covered with while poly-film (50 percent shade) from 20 November 1997 to 19 February 1998, and again from 17 November 1998 to 16 February 1999. Doors on either end of the film-covered structure were left open, unless temperatures below freezing were expected. Plants were irrigated as needed (well water, average pH 7.2 and average EC 0.25 dS/m). Shoots of *Rhododendron* were severed at the substrate surface on 30 March 1999 and dried to constant weight. Leachate samples were collected from three replicate pots for each fertilizer treatment on 31 March 1999, and measured for EC. Following checks for normality and homogeneity, data were analyzed for significance to fertilizer treatment using analysis of variance (SAS ANOVA).

Results

Rhododendron 'Getsutoku' had more shoot dry weight when grown using any application rate of Apex 20-10-10 compared to the twice-applied Osmocote 16-8-12 (Table 1). The low rate of Nutricote 16-10-10 also supported higher shoot dry weight compared to the Osmocote treatment. Higher rates of Nutricote 16-10-10 had smaller plants due to shoot die-back from high August daytime temperatures during the growing season in summer of 1998. Compared to all other fertilizer treatments, the 3.5 lb N/yd^3 rate of Apex 20-10-10 supported the most shoot growth.

We have obtained similar results with *Buxus* 'Winter Gem,' *Juniperus* 'Mint Julep,' *Pieris* 'Mountain Fire,' and *Thuja* 'Golden Globe' (data not shown).

Considering the cost of labor to top-dress fertilizers to support growth during the second 9-month set of an 18-month production cycle, a controlled-release fertilizer that supports the entire production cycle can cost considerably more per unit and still be cost effective. The combination of the Oregon climate (cool average temperatures during the growing season) and a polymer-coated fertilizer released based on temperature provided sufficient fertilization of the *Rhododendron* crop using a single application of controlled-release fertilizer.

At the end of the study (552 days after potting), only the Apex 20-10-10 at the highest rate had EC higher than the Osmocote 16-8-12 treatment, suggesting that all fertilizers other than the high rate of Apex 20-10-10 were no longer contributing to the fertilization of the crop.

Analysis of foliage samples found all mineral elements were in the "sufficient" range or higher for the Apex 20-10-10 fertilizer (data not shown). Nutricote 16-10-10 plants had no symptoms, but had some microelements below the "sufficient" range. For Osmocote 16-8-12, nearly all foliar elements were below the "sufficient" range. A different weather pattern during the study (natural rainfall was high during this experiment), and a different timing of the top-dress application of 16-8-12 may have produced different results.

Careful preparation of polymer-coated slow-release fertilizers may provide sufficient fertilization for 18 months of production of container-grown nursery crops in Oregon. Eighteen-month slow-release fertilizers eliminate the labor costs associated with split-applications of fertilizers with a shorter release time. Eighteen-month controlled-release fertilization was successful for selected clones of *Buxus*, *Juniperus*, *Pieris*, *Rhododendron*, and *Thuja,* suggesting that this fertilization procedure may have broad application potential in the Pacific Northwest growing region.

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Table 1. Shoot dry weight of 'Getsutoku' *Rhododendron*, and substrate leachate EC, 552 days after potting as influenced by controlled-release fertilizer treatment.

Fertilizer[1]	Application Rate (lb N/yd^3)	Shoot dry weight (g)	EC (dS/m)
Osmocote 16-8-12	2.4 (applied twice)	38.4 c[2]	0.33 b
Nutricote 16-10-10	2.4	47.5 ab	0.31 b
	3.2	43.9 b	0.34 b
	4.0	42.1 bc	0.37 b
Apex 20-10-10	2.75	45.4 b	0.41 ab
	3.75	49.0 a	0.44 ab
	4.75	46.9 ab	0.55 a

[1] Osmocote 16-8-12 (7 to 9 month formula) contained microelements and was incorporated at 2.4 lb N/yd^3, and then the same rate was applied as a topdress; Nutricote 16-10-10 contained no microelements and was a 15:20:20:45 (by weight) blend of types 70:100:180:270; Apex 20-10-10 contained microelements.
[2] Means in columns followed by the same letter are not significantly different ($P<0.05$) according to Fisher's Protected Least Significant Difference.

Controlling Root and Weed Growth in a Nursery Crop Sandbed Subirrigation System

Sven E. Svenson, Dave Adams (retired) and Robert L. Ticknor (retired)
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Introduction

Capillary irrigation uses less water than many irrigation systems, and reduces the quantity of fertilizer leaching from production beds. Sandbeds are a useful and inexpensive capillary irrigation system that can be used in a variety of situations (Clemens et al., 1991; Costin, 1988; Dean, 1986; Hicklenton and Cairns, 1995; Scott, 1991). Sandbed construction and use has been reviewed (Adams et al., 1997; Hicklenton and Cairns, 1993; Scott, 1985; Stanley and Baldwin, 1980; Svenson et al., 1997).

Roots growing into the sandbed after rooting-out from container drainholes, and weeds growing on the sandbed surface, are two major problems associated with the use of sandbed subirrigation systems. The objective of this study was to test various methods for controlling rooting-out and weed growth on sandbed subirrigation systems. Application of herbicides to the sandbed surface, water level below the sandbed surface, and placing untreated or copper hydroxide-treated weed barriers on the sandbed surface were tested to control rooting-out and weed growth.

Methods

In the first experiment, three replicate 2-ft by 3-ft plots of sandbed surface were sown with seeds of fireweed (*Epilobium* sp.) on 14 April 1994. Plots were treated the same day with Surflan AS (40.4% oryzalin; DowElanco, Indianapolis, IN) at 3 fl oz/1,000 ft^2, Snapshot 2.5 TG (trifluralin + isoxaben, DowElanco, Indianapolis, IN) at 5 lb/1,000 ft^2), or left untreated. Five *Daphne genkwa* in 1-gal containers were placed on each plot on 15 April. The number of fireweed growing in the plots was recorded on 17 June. *Daphne* height and shoot fresh weight, and weight of roots growing out of container drainholes were recorded on 23 September.

In the second experiment, the water level below the surface of the sandbed was regulated by raising the sand depth in selected plots by 2 inches, creating plots with the water level at the surface of the sandbed, or with the water level 2 inches below the surface of the sandbed. Three replicate 2-ft by 3-ft plots within each water level treatment were covered with 2.5 ounce non-woven filter fabric, with 2.5 ounce non-woven filter fabric treated with copper hydroxide (SpinOut™, Griffin Corp., Valdosta, GA) on the upper surface, or were left uncovered. Five *Forsythia* 'Lynwood' and *Erica* 'Ghost Hills' (2¼-in pots) were potted into 1-gal containers, and then placed on the surface of each plot on 25 June 1995. The number of fireweed growing in each plot was recorded. Shoot size [height + (width + width/2) /2] and weight of roots growing out of container drainholes of *Forsythia* and *Erica* was recorded the first week of October. All data were analyzed using analysis of variance, and means were separated using Duncan's Multiple Range Test.

Results

Both Surflan and Snapshot provided good control of fireweed growth on the surface of the sandbed (Table 1). *Daphne* shoots were shorter when grown on SnapShot-treated sandbed plots, but shoot weight was not influenced by herbicides. Both Surflan and Snapshot completely prevented rooting-out.

Using a low water level in the sandbed reduced the number of fireweeds by about one-third (Table 2). Use of treated or untreated weed barriers significantly reduced fireweed growth at both low and high water levels, with the copper-treated barrier improving weed control in the high water level treatment. Compared to all other treatments, *Forsythia* shoot size was smaller when grown on copper-treated barriers in the low water level plots. *Erica* shoots were larger when grown on barriers in the high water level plots. While rooting-out of *Erica* was eliminated by placing treated or untreated weed barriers on the sandbed surface, rooting-out of *Forsythia* was controlled only by copper-treated barriers (data not shown). Richards (1975) suggested that the water level in the sandbed could be regulated to prevent rooting-out. In our study, both *Forsythia* and *Erica* rooted-out on uncovered plots when the water level was at the surface of the sandbed, or when the water level was 2 inches below the sandbed.

We have obtained similar rooting-out results with *Pennisetum alopecuroides* and *Weigela* 'Java Red' (data not shown), and similar weed data for bittercress (*Cardamone* sp.).

When sandbed subirrigation is an acceptable option for nursery production, weed growth and rooting-out can be reduced or eliminated using either herbicide treatments or weed barriers placed on the sandbed surface. Since herbicides may not be labelled for this type of use, weed barriers are currently the best available option. Weed barrier pretreated with copper is presently available (Texel Industries, Spartanburg, SC), but the copper treatment may not be needed to control rooting-out for all crops.

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Literature cited

Adams, D., S.E. Svenson, and R.L. Ticknor. 1997. Making your bed. American Nurseryman 185(2):60-67.

Clemens, J., C.B. Christie, and C.J. Barnaby. 1991. Watering container plants five different ways. Proceedings of the International Plant Propagator's Society 41:98-102.

Costin, J.J. 1988. The capillary bed method of irrigating nursery stock. Proceedings of the International Plant Propagator's Society 38:335-338.

Dean, E.J. 1986. Capillary beds -- An early assessment. Proceedings of the International Plant Propagator's Society 36:458-462.

Hicklenton, P.R. and K.G. Cairns. 1993. Design and operation of an automated capillary irrigation system for production of containerized nursery plants. HortScience 28(5):562.

Hicklenton, P.R. and K.G. Cairns. 1995. Evaluation of four irrigation systems for containerized ornamentals. HortScience 30(4):895.

Richards, M. 1975. Felts for drained capillary benches. Comm. Hort. 7(2):5-6.

Scott, M.A. 1991. Efford sand beds II: Management and commercial use in the United Kingdom and Ireland. Ornamentals Northwest Seminars Handout, August, 1991.

Scott, M.A. 1985. Construction of Efford sandbeds. Ministry of Agriculture, Fisheries and Food, United Kingdom. Leaflet 902.

Stanley, J. and I. Baldwin. 1980. Standing grounds -- a key to successful container growing. American Nurseryman 152(1):24-25, 64.

Svenson, S.E., D. Adams, and R.L. Ticknor. 1997. Slow and Steady. American Nurseryman 185(2):50-59.

Table 1. Influence of Surflan and SnapShot application to sandbed surface on the number of fireweeds and on the growth of *Daphne genkwa*.

Treatment	Number of fireweeds (per ft^2)	*Daphne* shoot length (cm)	*Daphne* shoot fresh weight (g)
Untreated	25 a	40.9 a	24.9 a
Surflan AS	1 b	42.9 a	21.2 a
Snapshot 2.5 TG	0 b	35.3 b	25.4 a

Means within columns followed by the same letter are not significantly different (5 percent error level) according to Duncan's Multiple Range Test.

Table 2. Influence of water level below the sandbed surface, weed barrier on the sandbed surface, or copper-treated weed barrier on the sandbed surface on number of fireweeds (*Epilobium* sp.), shoot size of *Forsythia* 'Lynwood,' and shoot size of *Erica* 'Ghost Hills.'

Water level	Surface treatment	Number of fireweeds (per ft^2)	Shoot Size	
			Forsythia	*Erica*
Low	untreated	14 a	26 a	7 b
	barrier	3 bc	24 ab	8 b
	barrier + Cu	1 c	21 b	8 b
High	untreated	21 a	26 a	9 ab
	barrier	5 b	27 a	10 a
	barrier + Cu	1 c	25 a	10 a

Means within columns followed by the same letter are not significantly different (5 percent error level) according to Duncan's Multiple Range Test.

Suppression of *Marchantia* Growth in Containers Using Irrigation, Mulches, Fertilizers and Herbicides

Introduction

Marchantia species (usually *Marchantia polymorpha*) frequently infest the substrate surface of container grown ornamentals. A full mat of *Marchantia* can restrict the movement of irrigation water and fertilizers into the substrate, and reduces the marketability of the crop. Commercial herbicides and other products used for *Marchantia* control may be phytotoxic or may have limited effectiveness, and rarely have a use label that includes *Marchantia*. Hand removal is expensive and may damage crop roots. Use of preemergence herbicides has been suggested (Elmore et al., 1979), and they are effective for some woody crops (Clemens et al., 1991). Preventative techniques currently are being studied (Svenson, 1997). Since dead *Marchantia* on the surface of the growing substrate may be more unsightly than a live infestation, procedures and products that prevent *Marchantia* infestions are needed. The objective was to study how nursery practices influence the development of *Marchantia* infestation in container grown nursery crops.

Methods

A series of experiments was performed to study how irrigation practices interact with other cultural procedures to influence *Marchantia* development. The following procedures were the same for all experiments: (1) *Picea glauca* 'Conica' or *Rhododendron* 'Jean Marie Montague' growing in 4 in (10 cm) square pots were placed in a fiberglass covered greenhouse in September or November (Aurora, OR); (2) plants were spaced [6 in (15 cm) on center] to create four replicate blocks for high frequency irrigation (water daily) or low frequency irrigation (watered every 3 days) in a randomized complete block design; (3) five pots were used as an experimental unit for each treatment in each block; (4) after treatments were applied, pots were inoculated with *Marchantia* by pouring 50 ml of an inoculum slurry onto the surface of the growing substrate [slurry was made by placing 5 g (fresh weight) of *Marchantia* thalli with visible gemmae cups collected from infested pots in a commercial greenhouse, 50 ml of buttermilk, and 250 ml of water in a blender and mixing for 5 seconds]; (5) foliage was monitored for phytotoxicity; (6) *Marchantia* infestation was rated as the percentage of the substrate surface covered with live *Marchantia*; (7) all data were analyzed using analysis of variance following checks for normality and homogeneity. Percent data required square-root transformation for a valid analysis of variance. Mulches were applied at least ½ in (1.3 cm) thick. Herbicides were applied according to label instructions. Additional details are included with the data in each table.

Results

High frequency irrigation increased *Marchantia* coverage of the surface of the growing substrate (Tables 1 through 4). Increasing the amount of nitrogen from a 20N-9P-17K fertilizer increased *Marchantia* coverage (Table 1), with nitrogen levels from 100 to 200 mg/liter (ppm) supporting the most coverage. We have recorded increased *Marchantia* coverage in response to increasing nitrogen and increasing phosphorus application rates (data not shown), so the response to increasing rates of 20N-9P-17K may be due to the nitrogen, the phosphorus, or both.

Hazelnut shells, oyster shells, and copper-treated geotextile discs provided some suppression of *Marchantia* coverage for up to 6 weeks (table 2). Coarse sand, perlite, pumice, and untreated geotextile discs suppressed *Marchantia* establishment and growth under low frequency irrigation, but not under high frequency irrigation. With high frequency irrigation, *Marchantia* grew on the substrate surface below the untreated geotextile discs.

Surface applied microelement fertilizers and surface applied preemergent herbicides suppressed *Marchantia* growth with low-frequency irrigation (Table 3). However, high frequency irrigation eliminated or reduced the effectiveness of these treatments.

The combination of hazelnut shells and oxadiazon provided good suppression of *Marchantia* growth for up to 12 weeks with low frequency irrigation, and the combinations of hazelnut shells or pumice with oxadiazon provided suppression for 8 weeks with high frequency irrigation (Table 4).

Marchantia growth appears to be optimized by high frequency irrigation and nitrogen rates between 100 and 200 mg/liter (ppm). Reducing irrigation frequency improved the suppression of *Marchantia* by mulches, surface-applied fertilizers, or preemergent herbicides. None of the procedures tested in this study provided complete control of *Marchantia,* suggesting that there is a need to develop products with efficacy against *Marchantia.*

Literature cited

Clemens, J., C.B. Christie, and C.J. Barnaby. 1991. Watering container plants five different ways. Proceedings of the International Plant Propagator's Society 41:98-102.

Elmore, C.L., W.A. Humphrey, and K.A. Hesketh. 1979. Container nursery weed control, Leaflet 21059. Division of Agricultural Sciences, University of California, Davis, CA.

Svenson, S.E. 1997. Suppression of liverwort growth using cinnamic aldehyde. Proc. South. Nurs. Assoc. Res. Conf. 42:494-496.

Acknowlegements

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Table 1. Influence of irrigation frequency and fertilization rate on the percentage of media surface covered with liverworts. Four-inch pots filled with a 9:1 Douglas-fir bark:peat moss substrate and potted with *Picea glauca* 'Conica'; fertigated with 20-20-20 at every irrigation; leachate pH averaged 6.8.

Irrigation frequency	Fertilization rate (mg/liter)	Weeks After Treatment 4	8
		Percentage of substrate surface covered with liverworts (%)	
low	0	8	17
	100	17	59
	200	26	67
	400	28	51
high	0	12	34
	100	31	100
	200	34	100
	400	32	94
Significance (PR>F)[1]			
irrigation X mulch		0.05	0.01

[1] Analysis of variance indicated a significant interaction between irrigation frequency and fertilizer rate, indicating that irrigation practices influenced the response to fertilizer rate.

Table 2. Influence of irrigation frequency and surface mulch treatments on the percentage of media surface covered with liverworts. Four-inch pots filled with a 9:1 Douglas-fir bark:peat moss substrate and potted with *Picea glauca* 'Conica'; fertilized with 20-20-20 at 100 ppm N every third irrigation; leachate pH averaged 7.3.

Irrigation frequency	Mulch treatment	Weeks after treatment 3	6
		Percentage of substrate surface covered with liverworts (%)	
low	No mulch	16	55
	Hazelnut shells	0	4
	Oyster shells	0	7
	Coarse sand	0	35
	Peat moss	19	75
	Perlite	0	42
	Pumice	0	37
	Rockwool	17	67
	Geotextile disc	0	20
	Geotextile disc + copper	0	2
high	No mulch	22	100
	Hazelnut shells	0	8
	Oyster shells	0	9
	Coarse sand	0	78
	Peat moss	31	100
	Perlite	0	92
	Pumice	0	85
	Rockwool	29	100
	Geotextile disc	0	32
	Geotextile disc + copper	0	9
Significance (PR>F)[1]			
irrigation X mulch		0.05	0.01

[1] Analysis of variance indicated a significant interaction between irrigation frequency and mulch type, indicating that irrigation practices influenced the effectiveness of the mulch treatments.

Table 3. Influence of irrigation frequency, substrate surface-applied fertilizers or preemergent herbicides on the percentage of media surface covered with liverworts. Four-inch pots filled with a 9:1 Douglas-fir bark:peat moss substrate and potted with *Picea glauca* 'Conica'; fertilized with 20-20-20 at 100 ppm N every third irrigation; leachate pH averaged 7.2 for herbicide treatments, and 6.7 for fertilizer treatments.

Irrigation frequency	Surface treatment	Weeks after treatment 4	8
		Percentage of substrate surface covered with liverworts (%)	
low	untreated	12	34
	iron oxide (30 ppm Fe)	1	28
	copper sulfate (4 ppm Cu)	5	33
	manganese sulfate (4 ppm Mn)	3	26
	oxadiazon (4 lbs./1,000 ft^2)	0	12
	oryzalin (3 oz./1,000 ft^2)	0	17
high	untreated	21	92
	iron oxide (30 ppm Fe)	18	84
	copper sulfate (4 ppm Cu)	23	95
	manganese sulfate (4 ppm Mn)	16	82
	oxadiazon (4 lbs./1,000 ft^2)	14	45
	oryzalin (3 oz./1,000 ft^2)	17	67
Significance (PR>F)[1]			
irrigation X surface treatment		0.01	0.01

[1] Analysis of variance indicated a significant interaction between irrigation frequency and fertilizer rate, indicating that irrigation practices influenced the response to fertilizer rate.

Table 4. Influence of irrigation frequency and substrate surface-applied treatments on the percentage of media surface covered with liverworts. Four-inch pots filled with a 9:1 Douglas-fir bark:peat moss substrate and potted with *Rhododendron* 'Jean Marie Montague'; fertilized with 20-20-20 at 100 ppm N every third irrigation; leachate pH averaged 7.1.

Irrigation frequency	Surface treatment	Weeks after treatment 4	8	12
		Percent of substrate surface covered with liverworts (%)		
low	untreated	10	22	56
	peat moss + oxadiazon	5	18	33
	hazelnut shells + oxadiazon	1	3	12
	hazelnut shells + ferrous sulfate	2	5	17
	pumice + oxadiazon	1	3	15
	pumice + ferrous sulfate	3	7	22
high	untreated	16	100	98
	peat moss + oxadiazon	8	74	92
	hazelnut shells + oxadiazon	2	11	45
	hazelnut shells + ferrous sulfate	2	14	68
	pumice + oxadiazon	1	12	57
	pumice + ferrous sulfate	3	17	84
Significance (PR>F)[1]				
irrigation X surface treatment		0.01	0.01	0.01

[1] Analysis of variance indicated a significant interaction between irrigation frequency and fertilizer rate, indicating that irrigation practices influenced the response to fertilizer rate.

Using Quinoclamine and Meadowfoam Seed Meal to Control Liverworts in Containers

Introduction

Liverworts growing on the substrate surface of container grown nursery crops cause many problems. Liverworts compete with the crop plants for available fertilizers, particulary nitrogen and phosphorus. Mats of liverwort thallus prevent rapid penetration of irrigation water into the substrate, forcing water to flow down between the substrate and container surface and forcing growers to apply more water. Mats of liverwort thallus provide habitat for fungus gnats and shore flies, both of which have been shown to spread root rot-causing pathogens, and fungus gnat larvae are know to feed on the roots of many nursery crops. Unlike upright-growing weeds, liverwort infestations are very difficult to remove by hand. One nursery has estimated that liverwort control costs as much as 2 percent of gross sales receipts, which is a large portion of net profits.

The predominant liverwort species commonly infesting container grown nursery crops in the Pacific Northwest is *Marchantia polymorpha*. *Marchantia* spreads by airborne spores, splashed gemmae, and fragmentation, and rapidly infests moist substrate surfaces having adequate concentrations of nitrogen and phosphorus. A variety of strategies are being studied to reduce *Marchantia* infestations (Svenson, 1997; Svenson et al., 1997), because available herbicides have limited effectiveness in many situations (Svenson, 1998).

Quinoclamine (trade name Mogeton) is manufactured in Japan (Agro Kanesho Co. Ltd., Tokyo), and commonly sold in Japan and Northern Europe for control of liverworts. This product does not currently have any registered uses in the United States or Canada.

Meadowfoam (*Limnanthes alba*) is a winter rotational crop grown by Oregon's grass seed producers for extraction of high-valued oil. After the oil is extracted from harvested meadowfoam seeds, the seed meal is left over as a waste product. Our initial investigations suggested that meadowfoam seed meal was useful for control of selected plant pathogens, pests, and weeds.

The objective of this study was to determine if quinoclamine or unprocessed meadowfoam seed meal were useful for control of *Marchantia* infesting container grown *Rhododendron*.

Methods

Rhododendron 'Cannon's Double' (2 ¼-in liners) were potted into trade 1-gal pots filled with a 100 percent Douglas-fir bark substrate on 30 September 1999. The substrate was amended with 8 lb dolomitic limestone per cubic yard of substrate (pH 2 weeks after potting was 6.6). After potting, plants were topdressed with 12 grams of Nutricote 16-10-10 (1:3 by weight blend of type 40 and type 100). Thirty days after potting, all pots were inoculated with a *Marchantia* slurry composed of *Marchantia* gemmae and thallus blended with buttermilk and water (Svenson, 1998). Plants were grown in an unheated hoop structure covered with white poly-film (50 percent shade).

On 10 December, all pots were infested with *Marchantia*. Pots were treated with over-the-top sprays of quinoclamine at 1.1 or 2.2 oz ai/1000 ft^2, substrate topdress applications of unprocessed meadowfoam seed meal at ¼ cup or ½ cup per pot, or left untreated. The percentage of the substrate surface covered with *Marchantia* was evaluated 15, 30, and 60 days after treatment. The experiment was a randomized complete block design, using three pots as subsamples within each of five blocks. Following analysis for normality and homogeneity, data was analyzed using analysis of variance, with means separated using Duncan's Multiple Range Test.

Results

Both quinoclamine and meadowfoam seed meal provided excellent control of *Marchantia* at 15 and 30 days after application (Table 1), but good control was lost by 60 days after treatment. While meadowfoam seed meal provided good residual control of *Marchantia* 30 days after treatment, quinoclamine provided slightly better control of *Marchantia* than meadowfoam seed meal 60 days after treatment. There was no phytotoxicity to *Rhododendron* from either control product at the rates tested.

Since 1998, we have tested quinoclamine on many nursery crops including: *Aster*, *Dianthus*, *Helianthemum*, *Hypericum*, *Kalmia*, *Picea*, *Rhododendron* and *Sequoia*. Only the *Helianthemum* (cultivar 'Orange Surprise') exhibited symptoms of phytotoxicity, with leaf burn similar in appearance to damage caused by acetic acid (vinegar) application. In some experiments where irrigation application is frequent, the 1.1 oz ai/1000 ft^2 rate of quinoclamine failed to provide any control of *Marchantia*.

Meadowfoam seed meal had several qualities that were objectionable: (1) there was a tendancy for meadowfoam-treated pots to grow grass; (2) meadowfoam seed meal-treated pots had an objectionable odor; and (3) meadowfoam seed meal-treated pots tended to grow a whitish fungus on the surface of the treated pots.

To our knowledge, this is the first report of the efficacy of quinoclamine for control of *Marchantia* in container nursery crops in the United States. Similarly, this is the first report of the efficacy of meadowfoam seed meal for control of *Marchantia*.

Consistent with data from northern Europe, quinoclamine appears to be a useful herbicide for controlling *Marchantia*, but registration with the U.S. EPA is needed. Meadowfoam seed meal appears to be a useful material for *Marchantia* control, but registration with the U.S. EPA is still needed. The objectionable qualities of meadowfoam seed meal need to be processed out of the product before it will be marketable to the nursery industry. While quinoclamine provides a traditional herbicide spray for *Marchantia* control, meadowfoam seed meal provides a natural alternative product for *Marchantia* control.

Literature cited

Svenson, S.E. 1997. Suppression of liverwort growth using cinnamic aldehyde. Proc. South. Nurs. Assc. Res. Conf. 42:494-496.

Svenson, S.E. 1998. Suppression of liverwort growth in containers using irrigation, mulches, fertilizers, and herbicides. Proc. South. Nurs. Assc. Res. Conf. 43:396-402.

Svenson, S.E., B. Smith, and B. Briggs. 1997. Controlling liverworts and moss in nursery production. Comb. Proc. Intl. Plant Prop. Soc. 47:414-422.

Table 1. Influence of quinoclamine and meadowfoam seed meal on the percentage of substrate surface covered by *Marchantia*.

Product	Application Rate[1]	Days after application		
		15	30	60
Untreated		80 a[2]	85 a	100 a
Quinoclamine	low	0 b	4 b	18 cd
Quinoclamine	high	0 b	0 c	10 d
Meadowfoam	low	0 b	0 c	32 b
Meadowfoam	high	0 b	0 c	22 bc

[1] Quinoclamine rates were: 1.1 (low) or 2.2 oz ai per 1,000 ft^2; meadowfoam seed meal rates were: ¼ cup per pot and ½ cup per pot.
[2] Means in columns followed by the same letter are not significantly different at the 5 percent level according to Duncan's Multiple Range Test.

Limnanthes Seed Meal Efficacy on Beneficial Soil Microorganisms and on Fungus Gnats

Introduction

Limnanthes alba (commonly called meadowfoam) is a winter rotational crop grown by Oregon's grass seed producers for extraction of high-valued oil. After the oil is extracted from harvested meadowfoam seeds, the seed meal is left over as a waste product. Our initial investigations suggested that meadowfoam seed meal was useful for control of selected plant pathogens, pests, and weeds. The objectives of this study were: to determine if *Limnanthes* seed meal used as a growing substrate biomulch will influence the root and shoot growth responses of ornamental plant taxa; to determine if *Limnanthes* seed meal will influence the activity of *Tricherderma harzianum* Rifai strain KRL-AG2 (Trade name RootShield); to determine if *Limnanthes* seed meal will influence the population of fungus gnats present in a typical substrate used for nursery crop production.

Methods, Experiment 1

Geranium 'Claridge Druce,' *Hosta* 'Trumpet,' *Lobelia* 'Rose Beacon,' *Quercus robur* 'Fastigiata,' and *Tiarella* 'Tiger Stripe' were potted into 2.75 liter (1 gal) black plastic nursery containers filled with a Douglas-fir bark substrate. Apex 20-10-10 controlled-release fertilizer was incorporated into the substrate before potting at a rate of 12 g per pot. Plants were place in a polycarbonate-glazed greenhouse (natural photoperiod in May to July, Portland, OR). Under white-wash shading, the light quantity in the greenhouse averaged 500 $\mu mol\ m^{-2}\ s^{-1}$ at 12:00 noon, and the temperatures ranged from 16 to 32°C. Plants were irrigated as needed with overhead handwatering. After 7 days, pots were treated with *Trichoderma harzianum* Rifai strain KRL-AG2 (RootShield also sold as BioTrek T-22 or T-22 Planter Box, Bioworks, Inc., formerly TGT, Inc.), a biological fungicide, by drenching (sprenching) all pots with 6 oz of product per cubic yard of substrate using a hand-pump sprayer. Four days after drenching, pots were top dressed with *Limnanthes* seed meal at 0, 0.25, 0.5, or 1.0 cups per pot. Each rate of *Limnanthes* seed meal was represented by three pots in each of five randomized blocks. After 3 weeks, soil samples were collected from each pot and sent to a commercial laboratory to determine if the *Trichoderma* could be recovered from the substrate. Plants were observed throughout the experiment for symptoms of phytotoxicity to *Limnanthes* seed meal. The experiment was a randomized complete block design.

Methods, Experiment 2

Geranium 'Claridge Druce' were potted into 2.75 liter (1 gal) black plastic nursery containers filled with a moss peat:perlite (80:20, by volume) substrate. Osmocote 15-10-10 (3-month) controlled-release fertilizer was incorporated into the substrate before potting at a rate of 5 g per pot. Containers were surface sealed using a double layer of cheesecloth placed over the container, sealed around the plant stem with wax, and placed in a polycarbonate-glazed greenhouse (natural photoperiod in May to July, Portland, OR). Under white-wash shading, the light quantity in the greenhouse averaged 500 $\mu mol\ m^{-2}\ s^{-1}$ at 12:00 HR, and the temperatures ranged from 16 to 32°C. Plants were irrigated as needed with overhead handwatering. After 7 days, 10 fungus gnat larvae collected from nearby naturally-infested substrates (Harris et al., 1995) were placed 10 per pot in each pot, and the containers were resealed with cheesecloth. Three days after fungus gnat larvae were added, four rates of *Limnanthes* seed meal were topdressed on the surface of the substrate: 0, 0.25, 0.5, or 1.0 cup per pot, and the containers were resealed with cheesecloth. Each rate of *Limnanthes* seed meal was represented by 10 pots. After 6 weeks, potato disks measuring about 1 cm thick and 10 cm in diameter were placed on the surface of the substrate in each pot. After 5 days, the disks were removed and the number of fungus gnat larvae under the disk, and on the substrate surface under the disk, were counted. 'Claridge Druce' were observed throughout the experiment for symptoms of phytotoxicity to *Limnanthes* seed meal. The fungus gnat experimental procedure is very similar to that published by Evans et al. (1998). The experiment was a randomized complete block design.

Results, Experiment 1

Table 1 summarizes the data from experiment 1. *Limnanthes* seed meal generally reduced the recovery of *Trichoderma* from the substrate. The data suggest that use of *Limnanthes* seed meal may not always be compatible with the use of biological fungicides at the rates tested in this study.

Geranium, *Lobelia,* and *Tiarella* plants died when the *Limnanthes* seed meal rate was above 0.25 cup per pot, and there was no detectable difference in growth when untreated and 0.25 cup *Limnanthes* seed meal-treated plants were compared. There were no growth differences or symptoms of phytotoxicity for any rates of *Limnanthes* seed meal for *Quercus*.

Results, Experiment 2

Table 2 summarizes the data from experiment 2. All rates of *Limnanthes* seed meal reduced the number of recovered fungus gnat larvae. However, large numbers of adult fungus gnats were observed on the surface of the cheesecloth covering the *Limnanthes* seed meal-treated pots, suggesting that while the larvae may be suppressed, the *Limnanthes* seed meal attracted fungus gnat adults. Our recovery rates for fungus gnat larvae were comparable to those obtained by Evans et al. (1998). Additionally, *Limnanthes* seed meal application was accompanied by an odor, which some people may find objectionable.

While the *Limnanthes* seed meal does have significant control potential for soil borne larvae of fungus gnats, its ability to attract adult fungus gnats needs further study before this product can be suggested for use in controlling fungus gnat populations.

If more than 0.25 cup of *Limnanthes* seed meal per pot was applied, 'Claridge Druce' geraniums died. There was no difference in plant growth between untreated geraniums and geraniums treated with 0.25 cup of *Limnanthes* seed meal. Weeds (grasses) were common in *Limnanthes* seed meal-treated pots.

Because of the influences of environment, timing, and the life cycles of *Trichoderma* and *Bradysia* spp., caution needs to be emphasized in interpreting these experiments, as a single study can provide misleading results. Our data suggest that *Limnanthes* seed meal is a potent bio-rational product with the potential to regulate populations of insects and microorganisms. Additional study is needed before routine use of *Limnanthes* seed meal can be suggested for greenhouse or nursery operations.

Literature cited

Evans, M.R., J.N. Smith, and R.A. Cloyd. 1998. Fungus gnat population development in coconut coir and *sphagnum* peat-based substrates. HortTechnology 8(3):406-409.

Harris, M.A., R.D. Oetting, and W.A. Gardner. 1995. Use of entomopathogenic nematodes and a new monitoring technique for control of fungus gnats, *Bradysia coprophila* (Diptera: Sciaridae), in floriculture. Biol. Control 5:412-418.

Table 1. Influence of *Limnanthes* seed meal on persistence of *Trichoderma harzianum* Rifai strain KRL-AG2 in 2.75-liter containers (1 gal nursery containers) filled with a Douglas-fir bark substrate and potted with selected taxa.

Taxa	Rate[1] of *Limnanthes* seed meal	Percentage of pots containing *Trichoderma*	PR>F[2]
Geranium 'Claridge Druce'	0	80.2+8.1	0.0001
	0.25	60.2+6.8	
	0.50	26.4+6.6	
	1.00	6.6+6.6	
Hosta 'Trumpet'	0	60.2+6.8	0.0016
	0.25	53.4+8.3	
	0.50	26.4+6.6	
	1.00	13.2+8.1	
Lobelia 'Rose Beacon'	0	73.6+6.6	0.0002
	0.25	66.8+10.6	
	0.50	26.4+6.6	
	1.00	6.6+6.6	
Quercus robur 'Fastigiata'	0	60.0+12.6	0.0005
	0.25	53.4+8.3	
	0.50	19.8+8.1	
	1.00	6.6+6.6	
Tiarella 'Tiger Stripe'	0	73.0+12.5	0.0001
	0.25	60.2+6.8	
	0.50	19.8+8.1	
	1.00	0.0+0.0	

[1] *Limnanthes* seed meal applied at 0, 0.25, 0.5, or 1 cup per container as a topdressing.
[2] ANOVA F-test; data suggests regression analysis would be appropriate.

Table 2. Influence of *Limnanthes* seed meal rate on the number of fungus gnat (*Bradysia* spp.) larvae recovered in containers filled peat:perlite (80:20, by volume) and potted with *Geranium* 'Claridge Druce.' Ten fungus gnat larvae were placed in each pot before *Limnanthes* seed meal treatments were applied.

Limnanthes seed meal application rate[1]	Number of fungus gnat larvae recovered per pot
0.00	5.8+0.8
0.25	0.4+0.4
0.50	0.0+0.0
1.00	0.0+0.0
Significance (PR>F)[2]	
Limnanthes seed meal	0.0001

[1] Meadowfoam seed meal applied at 0, 0.25, 0.5, or 1 cup per pot as a topdressing.
[2] ANOVA F-test.

Flowering Sequence and Duration of *Pieris* Clones in Zone 8 in 1999

Introduction

Pieris are used in landscapes for the pitcher-shaped white, pink, or maroon flowers in spring, the colorful young growth of some cultivars, and the colorful young flower buds in winter. Depending upon species and location, common names vary from Andromeda to Fetterbush to Lily-of-the-Valley Shrub. There is still some discussion about correct taxonomic names and correct spellings for many cultivars. For this study, species designations are not used, and we use clonal spellings common to the United States. The majority of the clones are selections of *Pieris japonica*, and the remainder of the clones represent a mixture of species and species hybrids.

Knowledge of the flowering sequence and duration of different clones of *Pieris* would allow for planting landscapes with a collection of clones to provide an extended flowering period. Based on a review of the literature, the flowering sequence and duration of *Pieris* clones has received little study, or has not been reported (van Gelderen, 1979).

Clones of *Pieris* established at the North Willamette Research and Extension Center were used for this study. The study site has the following characteristics: latitude 45 degrees 17 minutes north and longitude 122 degrees 45 minutes west; elevation 150 feet above sea level; average last freeze date is April 17; average first freeze date is October 25; Clackamas County, Oregon. The weather records for this site can be viewed on the internet (http://mac1.pn.usbr.gov/agrimet/ -- select the Aurora, OR location). The AgriMet network weather station is located within 120 yards of all the plants used in this study, and within 40 yards of the majority of the plants. All plants used for this study were growing under full sun conditions in a Willamette silt loam soil.

Since 1997, we have recorded the date of first open flower, and the date when 50 percent of the flowers had turned brown or aborted (end of useful flowering duration, and the time when many landscapers will remove flower racemes). Following a procedure similar to den Boer (1995) for crabapples, we calculated a Bloom Time Index based on flowering sequence relative to the first clone to bloom each year. The BTI for a particular *Pieris* clone represents the average number of days after the first *Pieris* clone has its first open flower. Similar to den Boer (1995), we separated the clones into five flowering sequence categories: Very Early, Early, Mid-Season, Late, and Very Late.

Results

The sequence of first open flower was consistent for 1997, 1998, and 1999. Actual flowering start dates and duration of flowering were not the same in all 3 years. Only the data for 1999 are presented.

'Pygmaea' is the first clone with an open flower, and has the longest flowering duration. The BTI of other clones was determined relative to the flowering date of 'Pygmaea.' Our 29-year-old specimen of this clone is 4.5 ft tall. Smaller specimens are more likely to abort flower buds during winter and flower for a shorter period of time.

During one year with a mild spring and summer, this specimen flowered irregularly through August, for a flowering duration of nearly 6 months.

Very Early clones start flowering 1 to 3 weeks after 'Pygmaea' (Table 1). Many of the early flowering clones have pink or pink-bicolor flowers, whereas most *Pieris* clones have white flowers.

Early flowering clones bloom 3 to 4 weeks after 'Pygmaea' (Table 1). Similar to the Very Early category, many of these clones have pink or pink-bicolor flowers.

Mid-Season clones bloom 4 to 6 weeks after 'Pygmaea' (Table 1). This set includes the clones most often produced by the U.S. nursery industry. Van Gelderen (1979) noted that 'Purity' flowered 3 to 4 weeks later than "most other cultivars," and most of the clones commonly used in 1979 were classified as Very Early or Early in our study. A clone named 'Pygmy' produced only one flower in 1999 (no flowers in 1997 or 1998), and would be placed in the Mid-Season category. Our seedling selection of *Pieris formosa* var. *forrestii* had a BTI of 36 and a flowering duration of 72, placing it in the Mid-Season category.

Late clones start flowering 6 to 8 weeks after 'Pygmaea,' while Very Late clones bloom more than 8 weeks after 'Pygmaea' (Table 2). Most of the Late and Very Late *Pieris* clones have white flowers, and generally have a short flowering duration compared to Mid-Season or Early flowering clones. All of the "semi-dwarf" *Pieris* selections named from the seed collected by Robert de Belder on Yakushima Island in 1970 (clones of *Pieris japonica* var. *yakusimensis*) were Late or Very Late bloomers. Our selections of *Pieris japonica* var. *amamiana* and *Pieris japonica* var. *koidzumiana* flowered with other Late blooming *Pieris*.

Flowers of Late and Very Late clones are very susceptible to browning from a late frost. These clones should be grown under light shade where overhead tree canopies can provide some protection from clear-sky frosts. Most clones start flowering a week or two later when grown under shade, and may not produce flowers under heavy shade. All clones produced more flowering racemes the following spring when seed pods were removed (dead heading) in early summer, an observation that is consistent with the comments of others (Bond, 1982).

An interesting landscape effect can be created by randomly removing about one-third of the flower buds in the fall. This allows the disbudded shoots to initiate vegetative growth the following spring while the other shoots are still in full bloom. For clones with colorful new growth, the combination of flowers and colorful new growth can make a nice seasonal landscape feature.

Depending upon the weather patterns, some of the Very Early clones will start flowering like an Early clone, and the Very Late clones may bloom with the Late clones. This usually happens when both winter and spring are colder or warmer than normal, and the overall *Pieris* flowering season is shorter.

Clones that are species hybrids tended to flower Mid-Season or later (for example: 'Brouwer's Beauty,' 'Firecrest,' 'Forest Flame' and 'Valley Fire').

The 45 clones represented in this study include most of the clones grown by the U.S. nursery industry. A few popular clones have not yet been evaluated, including: 'Bert Chandler,' 'Blush,' 'Charles Michael,' 'Grayswood,' 'Henry Price,' 'Jermyns,' 'March Magic,' 'Pink Delight,' 'Red Head,' 'Red Volcano,' 'Rowallane,' 'Select,' 'Temple Bells,' 'Tilford,' and 'Wakehurst.' Flowering data for more than 50 other unnamed clones has been recorded.

This is the first report of the flowering sequence and duration for available *Pieris* clones. Flowering may differ in different climate zones. As additional data is collected, a prediction model based on degree-days may be useful in predicting the flowering season of selected *Pieris* clones. In USDA hardiness zone 8, careful *Pieris* cultivar selection for landscape use could provide a flowering season of 4 to 5 months or longer.

Literature cited

Bond, J. 1982. Pieris – A survey. The Plantsman 4:65-75.

den Boer, J.H. 1995. Blossom times. Malus 9(1):16.

van Gelderen, D.M. 1979. Pieris. Dendroflora 15/16:36-44.

Table 1. Bloom Time Index (BTI) and flowering duration of selected *Pieris* clones flowering Very Early through Mid-Season.

Clone	BTI-1999	Flowering Duration in 1999 (number of days)
	Very Early	
'Pygmaea'	0	112
'Daisen'	16	69
'Christmas Cheer'	18	78
'Flamingo'	18	92
'Spring Snow'	20	61
'Variegata'	20	85
'Valentine's Day'	20	92
	Early	
'Benihaja'	23	61
'Dorothy Wyckoff'	24	85
'Stockman'	24	92
'Wada'	24	92
'Snowdrift'	24	95
'Scarlett O'Hara'	26	109
'Valley Rose'	27	71
'Valley Valentine'	28	78
	Mid-Season	
'Shojo'	31	80
'White Cascade'	31	87
'Brookside Bonsai'	33	57
'Iseli Cream'	33	71
'Mountain Fire'	33	74
'Coleman'	33	81
'Purity'	33	81
'Karenoma'	33	98
'Gavotte'	37	52
'Firecrest'	37	74
'Forest Flame'	37	94
'La Rocaille'	37	94
'Red Mill'	37	103
'Little Heath'	39	84
'White Water'	39	84
'Brouwer's Beauty'	39	94

Table 2. Bloom Time Index (BTI) and flowering duration of selected *Pieris* clones flowering Late to Very Late.

Clone	BTI-1999	Flowering Duration in 1999 (number of days)
	Late	
'Compact Crimson'	52	52
'Debutante'	52	66
'Flaming Silver'	52	66
'White Caps'	52	66
'Chaconne'	52	81
'Nocturne'	52	81
'Ticknor's First'	52	81
'Mouwsvila'	56	66
'Prelude'	57	67
'Valley Fire'	57	77
	Very Late	
'Sarabande'	59	59
'Cavatine'	59	74
'Cupido'	59	74
'Bolero'	66	67

Using Flat-Roof Retractables for Winter Protection of Container Grown Nursery Crops

Introduction

The use of unheated systems for winter protection of container grown nursery stock has been studied (Regan et al., 1990), but unheated retractable roof systems were not available during earlier research. Using facilities at two commercial nurseries and at the North Willamette Research and Extension Center (NWREC), the ability of flat-roof retractable systems to provide unheated cold protection for container grown nursery stock was compared to seasonally-covered poly film structures, or no-cover.

On 20 June 1999, 1-year-old potted liners (2 ¼ in pots) of *Liquidambar styraciflua* 'Ward' were potted into trade 1-gal containers filled with an unamended Douglas-fir bark substrate. Pots were top-dressed with 16 grams of Apex 20-10-10 controlled-release fertilizer, and placed in a 17 x 96-ft hoop structure covered with black shade cloth (30 percent shade) for the summer growing season. Plants were irrigated as needed. These plants were located at a research nursery site near Aurora, OR (NWREC).

On 16 November, the hoop structure was covered with a single layer of white poly-film (50 percent shade plus 30 percent shade from the shade cloth for a total shading factor of 65 percent). On 17 November, one-third of the plants were moved to an uncovered growing area and one-third were moved to a 90 x 96-ft retractable roof structure using woven white poly-film as the glazing. Doors on the hoop structure were closed only when temperatures were below 32°F. The retractable roof structure was fully open unless temperatures were below 32°F, when it was fully closed. During cloudless, daylight hours, the retractable roof was placed in the "shading" position of 80 percent closed. In the hoop structure, plants were irrigated when needed, while uncovered plants and plants in the retractable roof structure received adequate irrigation from natural rainfall. The experiment was a split block treatment arrangement in a completely randomized design (n=20). Additional plants were located in structures and the outdoor growing area to simulate commercial nursery growing conditions.

Six thermocouples connected to data loggers were placed in each of the three environments to provide three replicated hourly measurements of air and substrate temperature. Substrate thermocouples were located 3 in below the substrate surface and 1 in away from the container side wall.

Thermocouples and recorders were placed in similar containers and structures on two commercial nurseries. The first nursery was located near Woodburn, OR and had 24 x 60-ft hoop structures covered with white poly film (50 percent shade) and 30 percent black shade cloth and a 6-acre retractable roof structure using the same film as the NWREC. The second nursery was located near Mt. Angel, OR and had 30 X 110-ft hoop structures covered with white poly film (50% shade) and a 14-acre retractable roof structure using the same film as the NWREC. Each nursery also had uncovered growing areas. The two nurseries and the research site provided three replicated measures of similar winter protection systems.

From 23 through 26 December, a freeze event occurred, allowing evaluation of the treatments. Daily maximum and minimum temperatures are reported. To measure the level of plant response to winter protection environment, *Liquidambar* plants were evaluated on 20 April 2000 for percentage of shoots exhibiting symptoms of die-back. Following analysis for normality and homogeneity, data were analyzed using analysis of variance (SAS ANOVA).

Results

Substrate temperatures varied less under cover compared to the substrate temperatures of unprotected containers (Table 1). At one site, substrate temperatures in unprotected containers reached maximums over 90°F within 12 hours of minimum temperatures below 25°F. Minimum air and substrate temperatures remained warmer in retractable roof structures compared to hoop covered or unprotected containers at all three nursery sites. A combination of a lower ratio of the glazing surface relative to covered ground surface in the retractables, a larger air mass in the retractables, and differences in the thermal properties of the film glazing probably contributed to warmer minumum temperatures in the flat-roof retractable structures compared to hoop structures. The study needs to be repeated during a more severe freeze event.

There was no shoot die-back of *Liquidambar* in the retractable roof structure, and die-back was more severe among uncovered plants compared to plants protected in the hoop structure (Table 2). This is the first replicated study showing improved plant health in retractable roof systems compared to other systems of unheated winter protection for container grown nursery crops. Testimonials from growers had previously indicated reduced inventory losses from winter damage when crops were protected using retractable roof systems. We have complete studies using over 30 nursery taxa (data not shown), and 5 of the 30 showed reduced inventory losses when protected using a retractable roof system.

At two commercial nurseries and at the NWREC, retractable roof structures provided the same or warmer unheated winter protection during a freeze event compared to poly-film covered hoop structures, and prevented cold-related damage to *Liquidambar*. Growers should consider the advantages of retractable roof systems carefully relative to the cost of the structures and the cost and price of nursery crops to be produced for sales.

Literature cited

Regan, R.P., R.L. Ticknor, D.D. Hemphill, Jr., T.H.H. Chen, P. Murakami, and L.H. Fuchigami. 1990. Influence of winter protection covers on survival and hardiness of container grown *Ilex crenata* Thunb. 'Green Island' and *Euonymus fortunei* (Turcz.) 'Emerald 'n Gold.' J. Environ. Hort. 8(3):142-146.

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Table 1. Daily maximum and minimum air and substrate temperatures (°F) at three sites during a freeze event (December 23 through 26, 1999) as influenced by winter protection system.

Date	site	Protection system	Air temperature max.	Air temperature min.	Substrate temperature max.	Substrate temperature min.
23	NWREC	unprotected	46	24	70	33
		hoop	49	27	44	32
		retractable	50	29	42	34
	Woodburn	unprotected	50	23	92	26
		hoop	54	29	52	30
		retractable	46	29	54	33
	Mt. Angel	unprotected	49	27	78	30
		hoop	66	28	55	32
		retractable	55	29	65	33
24	NWREC	unprotected	44	21	60	32
		hoop	44	25	38	32
		retractable	44	26	38	33
	Woodburn	unprotected	40	22	75	24
		hoop	47	27	46	29
		retractable	42	28	45	32
	Mt. Angel	unprotected	45	25	78	26
		hoop	65	28	50	31
		retractable	50	28	65	32
25	NWREC	unprotected	46	21	63	32
		hoop	46	25	40	32
		retractable	46	26	39	34
	Woodburn	unprotected	47	20	89	23
		hoop	49	26	47	28
		retractable	46	28	46	32
	Mt. Angel	unprotected	46	23	74	27
		hoop	65	26	52	31
		retractable	55	27	62	32
26	NWREC	unprotected	50	30	70	34
		hoop	50	30	45	34
		retractable	50	32	43	36
	Woodburn	unprotected	47	21	92	24
		hoop	49	27	47	29
		retractable	49	29	46	32
	Mt. Angel	unprotected	48	24	72	27
		hoop	65	26	52	31
		retractable	55	28	65	32

Table 2. Shoot die-back of *Liquidambar styraciflua* 'Ward' at the NWREC after over-wintering unprotected, in a white poly-film covered hoop structure, or in a retractable roof structure using woven white film as the glazing.

Winter protection structure	Shoot dieback (%)
unprotected	34.6 c[1]
hoop	12.8 b
retractable	0.0 a

[1] Means followed by the same letter are not significantly different ($P<0.01$) according to Fisher's Protected Least Significant Difference.

Using Flat-Roof Retractables to Reduce Substrate Temperatures of Container Grown Nursery Crops

Introduction

Compared to production under stationary or no shading, container grown nursery crops grown under retractable shading often show improved growth (Svenson et al. 1992; Svenson, 1998). We studied the possibility that an improved root zone temperature environment may contribute to improved growth under retractable shading systems using white poly-film as the glazing.

Methods

Liners (2 ¼-in potted) of *Coreopsis verticillata* 'Zagreb' and *Forsythia* 'Lynwood' were potted 11 June 1998 into trade 1-gal containers filled with unamended Douglas-fir bark. Plants were placed under no shading, under 30 x 96-ft hoop structures covered with 63 percent knitted black shade cloth, or under retractable roof structures using white woven poly-film (50 percent shade) as the glazing. Plants were top-dressed with Apex 20-10-10 controlled-release fertilizer at a rate supplying 2.25 lb N per cubic yard of substrate. Plants were irrigated as needed (unfiltered well water). Leachate pH ranged from 5.2 to 6.3 during the study.

The retractable roof system was operated using a photosensor to extend the poly-film shade (80% closed roof position) whenever natural sunlight exceeded 1,100 PPF (about 5,700 ft-c) for 20 minutes, and to retract the poly-film whenever sunlight remained below 1,100 PPF for more than 30 minutes. The system required 4 minutes to place the roof in the designated position.

Substrate temperatures were recorded by placing thermocouples attached to data recorders in the southwest quadrant of the rootball in three containers of *Forsythia* growing in each of the three growing environments. Thermocouples were placed 3 in down from the substrate surface, and 1 in inward from the container sidewall. Measured plants were located on the southwest corner of replicated experimental blocks. On 15 October, plant shoot height was recorded, and four plants from each of the three growing environments were harvested to determine shoot dry weight.

The study was a split-block treatment arrangement in a randomized complete block design. Data were checked for normality and homogeneity and then analyzed for significant differences to shading environment using analysis of variance. Means were compared using Fisher's Protected Least Significant Difference ($P<0.05$).

Results

On hot sunny days, highest daylight substrate temperatures were recorded in pots without shading, as represented by data for 15 August (Table 1). Containers under 63 percent black shade cloth had higher daylight substrate temperatures than containers under retractable shading (50 percent shading), but lower daylight substrate temperatures compared to containers without shading. Observations of the exterior of the root ball of plants grown without shading or under 63 percent shading revealed damage to roots (or no root growth) on the southwest quadrant of the root system, but there was no visible root damage to plants grown under retractable shading.

Coreopsis and *Forsythia* were taller when grown under 63 percent stationary shading compared to no shading or retractable shading, but had more shoot dry weight when grown under retractable shading (Table 2). Shorter stems with more shoot weight contribute to large plants with a compact growth habit when grown under retractable shading. The results are consistent with an earlier report for *Schefflera* grown in a sub-tropical environment (Svenson et al., 1992).

Cooler substrate temperatures that prevent damage to root systems may partially explain the increased growth of some nursery crops when produced under retractable shading systems using poly-film for the glazing. Containers growing under white woven poly-film providing 50 percent shading had cooler substrate temperatures compared to containers under black woven shade cloth providing 63 percent shade. Container grown *Coreopsis* and *Forsythia* had more shoot dry weight when grown under retractable shading compared to no shading or stationary shading.

Based on a review of the literature, this is the first report showing reduced substrate temperatures based on shading applied using a retractable roof system.

Compared to shade cloths, woven plastic films have been shown to increase the diffused proportion of incoming solar radiation (Healy and Rickert, 1998), which provides an increase in radiation flux on the lower shaded leaves supporting increased shoot growth (Healey et al., 1998). The increased shoot dry weight of *Coreopsis* and *Forsythia* under the retractable shading system used in our study may be the result of the diffusive capacity of the woven film plastic retractable roof.

Literature cited

Healey, K.D. and K.G. Rickert. 1998. Shading material changes the proportion of diffuse radiation in transmitted radiation. Aust. J. Expt. Agric. 38:95-100.

Healey, K.D., K.G. Rickert, G.L. Hammer, and M.P. Bange. 1998. Radiation use efficiency increases when the diffuse component of incident radiation is enhanced under shade. Aust. J. Agric. Res. 49:665-672.

Svenson, S.E., D.L. Johnston,and W.L. Schall. 1992. Faster growth of *Schefflera* using exterior retractable shading. Proc. South. Nurs. Assc. Res. Conf. 37:102-105.

Svenson, S.E. 1998. "Cold-trapping" in retractable roof structures to avoid spring frost damage on container-grown nursery crops. Proc. South. Nurs. Assc. Res. Conf. 43:107-112.

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Table 1. Influence of shading environment on substrate temperatures in containers on August 15, 1999. Air temperature at 3 PM was 101°F.

Time of day	Substrate temperature (°F)		
	No shading	Stationary black shade cloth	Retractable white poly-film
12 AM	82 a	84 a	79 a
3 AM	77 a	77 a	76 a
6 AM	73 a	73 a	72 a
9 AM	77 a	75 ab	72 b
12 PM	106 a	101 a	86 b
3 PM	120 a	108 b	94 c
6 PM	114 a	106 b	96 c
9 PM	101 a	98 a	90 b
12 AM	89 a	90 a	83 b

Means for each time (in rows) followed by the same letter are not significantly different using Fisher's Protected Least Significant Difference (P<0.05).

Table 2. Height and shoot dry weight of *Coreopsis verticillata* 'Zagreb' and *Forsythia* 'Lynwood' grown in trade 1-gal containers under no shading, stationary shading (63 percent shade from woven black shade cloth), or retractable shading (50 percent shade from woven white poly-film).

Species	Type of shading	Shoot height (cm)	Shoot weight (g)
Coreopsis 'Zagreb'	no shading	30.3 c[1]	14.1 c
	stationary	49.9 a	15.3 b
	retractable	39.0 b	18.5 a
Forsythia 'Lynwood'	no shading	52.1 c	26.0 c
	stationary	73.9 a	29.4 b
	retractable	61.2 b	39.9 a

[1] For each species, means in columns followed by the same letter are not significantly different using Fisher's Protected Least Significant Difference (P<0.05).

Using Flat-Roof Retractables for Spring Frost Protection of Container Grown *Pieris* Clones

Introduction

Nursery growers in many regions of the United States rely on unheated structures for winter protection of nursery crops. Single- or double-layered white poly-film covered structures, often quonset-shaped "hoop" houses, are commonly used for winter protection by many nurseries. White poly film is used to reduce heat build-up during sunny days, while still providing protection from frosts and freezing temperatures. In late winter and early spring, temperatures during sunny days in film covered structures can force early vegetative growth that is not cold acclimated. To avoid deacclimation and growth of cold-sensitive shoots, growers remove the white poly-film in late winter or early spring.

In Oregon's Willamette Valley, film typically is placed over structures about November 15 and removed about February 15. If a frost or freeze occurs earlier or later than normal, the uncovered crops are susceptible to damage. Labor costs and availability do not permit repeated application and removal of white poly-film to unheated structures.

One important advantage of flat-roof retractable systems using white poly-films is the ability to protect nursery crops from unseasonably early or late frosts or freezes, while still preventing the build-up of excessive heat during daylight hours. As part of other research, we observed this advantage in the Spring of 2000. The objective of this study was to compare the spring frost protection provided by the following: (1) no cover (control treatment); (2) white-film covered, unheated hoop houses; and (3) white-film covered, unheated, flat-roof retractable shade/cold protection structures.

Methods

Nine cultivars of *Pieris* were potted into trade 1-gal containers (2.5-liter volume) on 20 June 1999 using a 100 percent Douglas-fir bark substrated amended with 2.5 lb of Apex 20-10-10 controlled-release fertilizer. *Pieris* were grown in a retractable roof growing structure (white poly-film providing 50 percent shade). The roof typically was retracted (open) on overcast days, but positioned to provide shading typically from 10 AM to 5 PM on sunny days or days with broken clouds. The "shading" position for the roof was 20 percent open. Culture of plants followed standard nursery practices, except plants were not pruned.

On 20 October 1999, one-third of the plants from each cultivar were moved to an unprotected, outdoor growing area, one-third were moved into a hoop structure covered with black saran shade cloth providing 30% shade, and one-third were left in the retractable roof structure. White poly-film was pulled over the hoop structure on 16 November 1999 (film and shade cloth provided 65% shading). Doors were left open for ventilation, and closed by hand only when the weather forcast included the chance of air temperatures below 32°F. The retractable roof was left open or in the shading position (80 percent closed), and closed only when the weather forecast included the chance of air temperatures below 32°F. Film was removed from the hoop structure on 16 February 2000 (shade cloth remained in place). Plants were irrigated as needed during the winter protection cycle.

Plants in the hoop structure required three irrigation applications, while plants outside or in the retractable roof structure received sufficient water from natural rainfall (irrigation not required).

On 24 April 2000, a radiation frost occurred. Maximum, minimum, and average daily temperatures from 21 to 27 April are provided in Table 1. The retractable roof structure was left in the 20 percent open position from 1 April through 30 April. Air temperatures in the hoop structure and the retractable roof structure were the same as outside. On 2 May, frost injury to new shoots of *Pieris* was rated on a 0 to 10 scale, with 0 representing no damage and 10 representing 100 percent death of all new vegetative growth. Frost injury data were checked for normality and homogeneity, and then analyzed for significance to growing structure using analysis of variance (SAS ANOVA). Means were compared using Fisher's Protected Least Significant Difference ($P<0.05$). Each clone was analyzed as a separate experiment. The study used a completely randomized design with a split-block treatment arrangement.

Results

Only one significant freezing event occurred during the winter protection cycle. From December 22 through 28, air temperatures outside were as low as 24°F, but air temperature in the hoop structure and the retractable roof structure never fell below 32°F (data not shown).

Damage to *Pieris* from the 24 April frost is listed in Table 2. None of the *Pieris* growing in the retractable roof structure had any frost damage. The retractable film cover was sufficient to prevent frost injury even when placed in the 20 percent open position.

Pieris floribunda 'Karenoma' and *Pieris japonica* var. *yakusimensis* 'Prelude' had no frost injury, as these two clones had not yet initiated any new vegetative growth. *Pieris* x 'Valley Fire' had minimal frost injury in the outdoor growing area that was not significantly different from undamaged plants in the hoop or retractable roof structure.

Three *Pieris* clones had significant frost injury in the uncovered growing area, but injury to the same *Pieris* clones in the shade-covered hoop structure was not significantly different from the undamaged plants in the retractable roof structure: *Pieris japonica* 'Valley Rose,' *Pieris japonica* 'Flaming Silver,' and *Pieris* x 'Forest Flame.' 'Flaming Silver' and 'Forest Flame' were the only clones to show any frost injury to older leaves in the uncovered growing area.

Frost injury of *Pieris japonica* 'Valley Valentine' and 'Shojo' growing in the uncovered area was significantly different from the undamaged plants in the retractable roof structure. Plants of 'Valley Valentine' and 'Shojo' grown in the shade-covered hoop structure had injury intermediate between no damage and the amount of damaged that occurred in the uncovered area, but this was significantly different only for 'Shojo.'

Like 'Shojo,' *Pieris japonica* 'Mountain Fire' had frost injury to new vegetative shoot growth when growing in the uncovered area, and significantly more frost injury in the shade-covered hoop structure compared to the retractable roof structure. However, unlike 'Shojo,' frost injury of 'Mountain Fire' in the shade-covered hoop structure was similar to the frost injury in the uncovered growing area.

Since new vegetative growth of 'Mountain Fire' was initiated before new growth on 'Shojo' (growth of 'Mountain Fire' was chronologically older), the data suggests that the new growth of 'Shojo' may be more resistant to frost injury. Similarly, new growth of 'Valley Fire' started several weeks later than new growth of 'Flaming Silver' or 'Forest Flame,' but 'Valley Fire' had less frost injury in the uncovered growing area. This suggests that 'Valley Fire' is more resistant to frost injury compared to 'Flaming Silver' or 'Forest Flame.' In contrast, the new growth of 'Flaming Silver' and 'Forest Flame' was initiated before the new growth of 'Shojo' and 'Mountain Fire,' and had less frost injury. Overall, the data suggest that there is variation among clones for resistance of new vegetative growth to frost injury. However, the development of morphological and physiological resistance to frost injury may not be related to the chronological age of the new vegetative growth. Differing weather patterns prior to the frost event, among many other factors, may have produced different results.

Based on a review of the literature, this is the first report showing improved frost protection using a retractable roof system compared to other commonly used nursery production systems. We have obtained similar results using cultivars of *Kalmia latifolia* (data not shown). Similarly, shoot dry weights of *Pieris* and *Kalmia* were often significantly larger when grown in a retractable roof system compared to seasonal film and shade cover under a hoop structure, or compared to no cover (data not shown).

The retractable roof structure was the only structure to provide complete protection from frost injury of the new vegetative shoot growth of *Pieris,* preventing the loss of the initial spring growth flush. Since *Pieris* typically produce only two or three shoot growth flushes each year, the retractable roof system prevented the loss of from one-third to one-half of the growth for the year 2000. Growers must balance the economic advantages of good frost protection and other benefits of retractable roof structures with the higher initial costs of installation. Black shade cloth (30 percent shade) provided protection against frost injury for some clones of *Pieris*. There may be important variation in resistance of new vegetative growth to frost injury among *Pieris* clones, which may influence the clones a grower may select to produce.

Table 1. Minimum, maximum, and average daily temperatures for the week during a frost event in April 2000. There was no cloud cover from April 23 through April 25.

Date	Minimum temperature	Maximum temperature	Average daily temperature
4/21	41.06	65.22	52.48
4/22	41.98	54.22	48.11
4/23	36.28	51.95	46.00
4/24	31.58	55.84	44.75
4/25	40.99	55.47	49.10
4/26	39.31	68.33	54.11
4/27	42.44	60.15	50.37

Table 2. Frost injury ratings of *Pieris* clones growing in three different production environments.[1]

Clone	Uncovered	Shade covered structure	Retractable roof structure
'Flaming Silver'	6.2 a[2]	1.0 b	0.0 b
'Forest Flame'	5.6 a	0.4 b	0.0 b
'Karenoma'	0.0 a	0.0 a	0.0 a
'Mountain Fire'	8.8 a	6.8 a	0.0 b
'Prelude'	0.0 a	0.0 a	0.0 a
'Shojo'	9.2 a	3.4 b	0.0 c
'Valley Fire'	2.6 a	0.0 a	0.0 a
'Valley Rose'	7.8 a	0.6 b	0.0 b
'Valley Valentine'	6.2 a	3.8 ab	0.0 b

[1] Frost injury was rated on a 0 to 10 scale, with 0 representing no injury to new vegetative shoot growth, and 10 representing 100 percent death of new vegetative shoot growth.
[2] Means within rows are not significantly different at the 5 percent level, LSD; means in columns are not comparable.