Reduced Use of Pesticides for Effective Controls of Arthropod Pests and Plant Diseases[1]

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Abstract

Current label recommendations of pesticides for arthropod pests and plant diseases in the nursery and green industry are vague and frequently result in excessive pesticide use. The objective of this research was to demonstrate that modifications of spray application techniques with current spray equipment in ornamental nursery production could reduce pesticide use. The efficacy of half rates and full rates of both active ingredients and carrier was investigated in commercial nurseries with air-assisted sprayers in two tests and a state inspector survey for the control of arthropod pests and plant diseases. Sprayers were optimized with properly sized nozzles and properly calibrated operating parameters. In Test 1, treatments were conducted in approximately 0.5 ha (1.2 A) plot each in three commercial nurseries for control of arthropod pests and diseases, and in Test 2, the same treatment for aphid control was evaluated in a birch tree plot. The survey was a compilation of the pests and diseases that were diagnosed by state inspectors in over 2,800 plant varieties and species from two commercial nursery fields [total about 280 ha (692 A)] after the spray treatments in six growing seasons. Crop damage by 49 insects and 40 diseases were surveyed for different application rates. The studies revealed that insect and disease control using 50% of the label rates was as effective as full rates when quality spray coverage on targets was achieved, resulting in real cost benefits to producers, consumers and the environment.

Index words: air-assisted sprayer, application rate, pesticide reduction.

Significance to the Nursery Industry

This research demonstrated that growers could use their existing spray equipment to reduce pesticide and water use by 50% with properly changing spray nozzles at no extra cost and still achieve effective pest and disease control. This equates to doubling the pesticide application efficiency with reduced pesticide costs, reduced health risk to applicators, and diminished adverse impact to the environment. Other benefits accrued with this approach included increased operational efficiency (the area sprayed is doubled, the frequency and travel time required for the tank refilling times are reduced) and reduced costs for energy consumption and for new equipment, as well as reduced risk of pesticide exposure of workers.

Introduction

Pesticide applications to meet stringent market requirements are critical to ensure healthy, unblemished plants. Unlike field crops, nursery crops are grown in confined areas with many species, and their form, size, canopy structure and density vary greatly with the crops and production practices.

The recommended specification for application of each pesticide spray is one of the most complicated aspects of nursery crop production. Successful spray applications depend on the integration of delivery equipment and methods, compatibility of physicochemical properties of different sprays, diversity of crops and their growth habits, incidences of pests and diseases, operator skills, weather conditions, full compliance with worker safety and environmental regulations, and the economics of benefits of spray applications. Spray applicators are often confused by these variables when they must make a decision to spray or not to spray within a very narrow window in time. Consequently, a 'best guess' practice is often used in spray applications with vaguely labeled pesticides that result in excessive rates used for pest and disease control. Moreover, no spray equipment or method currently exists that can resolve all the complex problems involved in pesticide spray application systems.

Extensive research on orchard spray applications has been reported (2, 3, 4, 5, 6, 9, 10, 11, 12, 13). These findings also have been applied to spray applications for nurseries. Furthermore, studies were conducted to optimize the pesticide application technologies for spraying nursery shade trees (1, 8, 14, 15). Despite these efforts, significant reduction of pesticide use has not been achieved (7).

Secondly, the proximity of nurseries to residential areas confounds the safe practice of spray applications. Many nurseries are located adjacent to residential, urban or suburban areas and to their source of water. Given these constraints for spray applications in nurseries adjacent to human surroundings, delivery of the least amount of pesticides required to the target areas for effective control of pests and diseases is ideal.

Currently the practice that effective pest control can only be achieved when the target is saturated with sprays to the point of run-off is endorsed by growers. Unfortunately, judgment of the point of spray saturation on the target foliage varies among different growers' visual observations. Furthermore, spray droplets are small and can evaporate quickly. The time lapse for growers to visually determine the extent of the spray coverage on targets is sufficiently delayed so that the coverage will appear less than it actually is, which can further cause the canopy to be over sprayed. Also, high spray volume can lead to a greater chance of producing drift-potential droplets. It is normal for the same application rate to be used for the entire field regardless of

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the variation in crop size, shape and density in the field. An overspray of not less than four times the required amount with the 'point of run-off' method for adequate spray deposition and coverage inside the canopies of nursery trees has been reported (14, 15).

When trees are over sprayed with the carrier, they would also be over sprayed with the active ingredients, but no reports are found to reduce both carrier and active ingredients for nursery applications. This is because the current spray application practice only suggests the modification of carrier volume for preparations of spray mixtures, not the amount of active ingredients per unit area. This practice has been taught to growers and extension educators for many years to assure the volume of spray outputs but not spray coverage. Also, growers rely on superior plant quality to make a profit and may be concerned that reduction in pesticide use would reduce the quality of their products.

The hypothesis of this research was that, under commercial nursery production conditions, quality spray application with half the conventionally recommended volume of carrier and dosage of active ingredients would be sufficient to achieve effective pest and disease control. The objective of this research was to test the hypothesis under commercial nursery conditions, in an effort to establish effective programs for nursery growers to efficiently apply pesticides and minimize potential environmental pollution.

Materials and Methods

Comparisons of the full- and half-rate applications for control of insects and diseases were conducted in two types of tests and a state inspector survey in commercial nurseries. The full rate was the labeled rate and was used as the test control. The mid-point of the labeled rate was the full-rate preparation of the growers' preference of chemicals in the spray mixture. The half-rate spray application treatment of this mid-point rate was achieved with nozzles that reduced the flow-rate by half. All other operating parameters (e.g. sprayer travel speeds, spray swaths, operating pressures, spray mixtures, etc.) were the same for the half-rate and full-rate applications. Thus, the amount of active ingredient used for one hectare with the full-rate application was the same as the amount used for two hectares with the half-rate application.

To make this study more relevant, easily understood and more quickly adopted by growers, tests were conducted in commercial fields. Growers' resources, including spray equipment, spray operators, crops and production fields, were utilized. Because these tests were conducted on high value crops with growers' own risk of crop losses, spray application treatments were incorporated into their current practices including the targeted insects and diseases and timing of application.

In Test 1, the half-rate application for control of insects and diseases was tested in three, 0.5 ha (1.2 A) plots in 3 different commercial nurseries in 2 years. The rest of the production fields were treated with the full-rate application as the control. Crops in the test were crabapples (*Malus* × 'Spring Snow') in Nursery #1, weeping cherries (*Prunus subhirtella* 'Pendula'), red maples (*Acer* r. Franksred), crabapples (*Malus* 'Profusion') and katsuras (*Cercidiphyllum japonicum*) in Nursery #2, and serviceberries (*Amelanchier canadensis*) in Nursery #3. In Nursery #2, a 0.1 ha (0.25 A) plot of red maples (*Acer* r. Franksred) was a no spray treatment control. The test was conducted for one year in Nursery #3 and two years in Nurseries #1 and #2.

In Nursery #1, each side of a tower sprayer (Fig. 1a) was first fitted with 8 hollow-cone nozzles for full-rate [940 liters·ha^{-1} (100.4 gal·A^{-1}) nozzles] and then for half-rate [470 liters·ha^{-1} (50.2 gal·A^{-1}) nozzles] spray applications. In the Nursery #2, each side of another tower sprayer (Fig. 1b) was fitted with 9 hollow-cone nozzles. Because the trees were larger in the second nursery, 1,400 and 650 liters·ha^{-1} (150 and 69 gal·A^{-1}) application rates were used for the full- and half-rate fields, respectively. In Nursery #3, each side of a conventional air-blast sprayer was fitted with 7 hollow-cone nozzles. The full-rate and half-rate application rates were 1,035 and 520 liters·ha^{-1} (111 and 56 gal·A^{-1}) respectively. All nozzles were connected to the sprayers at the prescribed locations with a swivel T-adapter. Turning the swivel connection 180 degrees from its initial position changed the spray application rate from full-rate to half-rate. Water sensitive papers to detect the adequacy of spray deposition and coverage were placed inside the canopies for both application rates. Other parameters including sizes of plates and discs inside hollow cone nozzles, nozzle flow rate, operating pressure and travel speed for the three sprayers are shown in Table 1.

Three surveys for insect and disease damages to plants in the half- and full-rate plots were conducted during the growing season. Thirty leaves from the three top branches of each of six randomly selected trees of each plant variety or species were examined. The damage from insect or disease was rated at 0, 1, 2, 3, 4, and 5. A plant was rated 0 when no

(a) Nursery #1 sprayer **(b) Nursery #2 sprayer** **(c) Nursery #3 sprayer**

Fig. 1. Sprayers used for half- and full-rate applications in Test 1.

Table 1. Nozzle flow rate, pressure, travel speed and application rate used for half- and full-rate applications in three nurseries for Test 1.

Nursery	Application	Nozzle plate and disc[z]	Flow rate (liters·m^{-1})	Pressure (kPa)	Travel speed (km·h^{-1})	Application rate (liters·ha^{-1})
#1	Half-rate	D4-DC25	2.34	1450	6.4	470
#1	Full-rate	D5-DC45	4.70	1450	6.4	940
#2	Half-rate	D2-DC45	0.80	650	4.8	650
#2	Full-rate	D4-DC45	1.70	650	4.8	1400
#3	Half-rate	D3-DC35	2.35	1035	4.8	520
#3	Full-rate	D6-DC45	4.86	1035	4.8	1075

[z]Manufactured by Spraying Systems Co. (Wheaton, IL).

insect or disease damage was observed, it was rated a 3 when there was severe insect or disease damage but the leaves still grew, and rated a 5 when it was defoliated.

In Test 2, the half-rate treatment was tested for control of a heavily green aphid (*Aphis pomi*) infested 72 m (78.7 yds) wide and 100 m (109.4 yds) long silver birch (*Betula nigra*) tree plot. The plot contained nine equally spaced, 4.6 m (15.1 ft) wide sections, and each section contained 4 rows of birch trees (Fig. 2). The tree height averaged 3.1 m (10.2 ft) and within each section the branches almost overlapped. The plot was divided into two for half- or full-rate application treatments (Fig. 2). The same tower sprayer used for Nursery #2 as described above was used for the spray application treatments. The full-rate application for this plot was 1,400 liters·ha^{-1} (150 gal·A^{-1}) with a dosage of 0.548 liters·ha^{-1} (0.06 gal·A^{-1}) for the insecticide Talstar (FMC Professional Solutions, FMC Corporation, Philadelphia, PA), and the half-rate application was 650 liters·ha^{-1} (69 gal·A^{-1}) with 0.254 liters·ha^{-1} (0.027 gal·A^{-1}) dosage of the insecticide. The concentration of the insecticide in the spray mixture was 0.391 ml·liter^{-1} (v/v) for both half- and full-rate applications. The four rows of trees in each section were sprayed from both sides. Five branches from each of six trees in the middle two rows of each section were randomly selected to assess the aphid infestation before the spray treatment and at 3 and 12 days after the treatment.

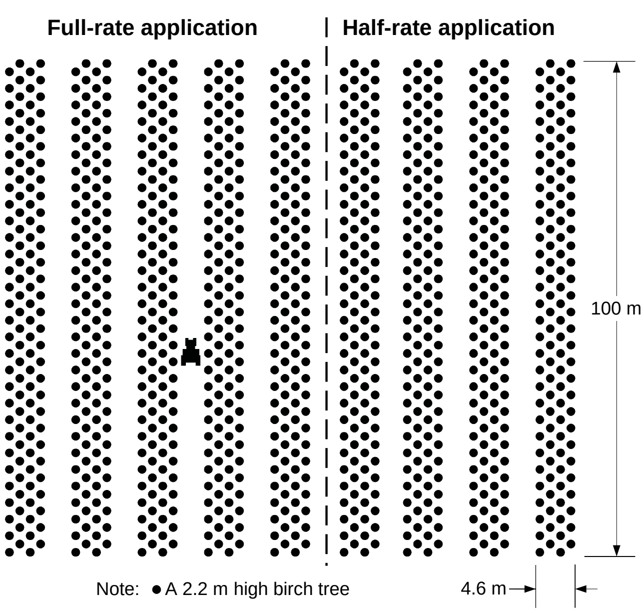


Fig. 2. Layout of a birch tree plot for aphid control in Test 2.

The state inspector survey was an evaluation of the full- and half-rate treatments on shade trees and container-grown woody ornamentals in two commercial nursery fields by state inspectors for six growing seasons. The nursery acreages were 175 and 125 ha (432.4 and 308.8 A), respectively, but the actual production area for each year changed. Although the half-rate treatment was not tested in nurseries in the preliminary trials on woody ornamentals, it was tested after water sensitive paper evaluations determined that adequate spray deposition and coverage were achieved. The same plant varieties or species of shade trees and container-grown woody ornamentals were planted at different locations throughout the nurseries.

In the first nursery field, crops were treated with the full-rate application in 2005 and 2006, and crops in the same field were treated with the half-rate application in 2007 to 2010. Spray treatments were applied with a modified air-blast sprayer (Fig. 3a) or a tower sprayer (Fig. 1b). The full-and half-rate applications with the modified air-blast sprayer were 795 and 370 liters·ha^{-1} (85 and 49 gal·A^{-1}), respectively. The full- and half-rate applications for the tower sprayer were 1,400 and 650 liters·ha^{-1} (155 and 69 gal·A^{-1}), respectively.

In the second nursery field, crops were treated with the full-rate spray application in 2006 and 2007, and with the half-rate spray application in 2008 to 2010. Spray treatments were applied with an air-assisted cannon sprayer (Fig. 3c). The application rates for the full- and half-rate were 430 and 206 liters·ha^{-1} (46 and 22 gal·A^{-1}), respectively.

During each of the six growing seasons, State inspectors evaluated and classified the treated plants by variety or species and determined the prevalence, severity, kind and type of pest infestations and disease occurrences. Forty-nine arthropod species and 40 plant diseases were identified in approximately 2,800 plant varieties and species. Some pests and diseases were identified every year while some were identified in only one or two years. Fourteen insecticides and 8 fungicides were used in the full- and half-rate treatments. Damages were rated at three levels: light, moderate and severe. Rating level was light when a few leaves had insect or disease damages while the entire plant was still healthy, and the severe rating level indicated over 50% leaf area had insect or disease damages but the leaves still grew, and a moderate rating level was between light and severe damages.

Results and Discussion

Test 1. The spray deposition and coverage results on water sensitive papers demonstrated that full- and half-rate spray applications inside the plant canopies of all three nurseries were excessive (Fig. 4). That is, plant leaves were excessively covered by spray deposits with the full-rate application and

(a) FMC airblast sprayer (b) Tower sprayer (c) Cannon sprayer

Fig. 3. Sprayers used for state inspector survey with full- and half-rate applications in two nursery fields. Sprayers shown in (a) and (b) were used in the first field and the sprayer shown in (c) was used in the second field.

more than adequately covered with the half-rate application.

For the first year trial in Test 1, an infestation of aphids (*Aphis pomi*) was detected for crabapple trees in Nursery #1. In Nursery #2, an infestation of Japanese beetles (*Popillia japonica*) was detected in weeping cherry trees, leafhoppers (*Cicadellidae*) in red maples, spider mites (*Tetranychidae*) in crabapples, and no insect infestations in katsura trees. In Nursery #3, spider mites (*Tetranychidae*) were found in serviceberries. Table 2 shows the comparisons of percentages of insect infestations between the full- and half-rate applications in the trial of the first year. In Nursery #2, 50% weeping cherries were infested by Japanese beetles at ratings 3 and 4 in the full-rate application field while 14% leaves were infested at ratings 1, 2 and 4 in the half-rate application field. Also, 14% leaves of red maples were infested by leafhoppers at ratings 2 and 3 in the full-rate field and 5% leaves were infested at rating 1 in the half-rate field. Except for these high-rate infestations, all other plants in all three nurseries fared very well and had minimal damage from insect infestations in fields treated at either half or full rate in the first year trial. For comparison, the leafhopper infestation on red maples in the untreated plot was rated a three.

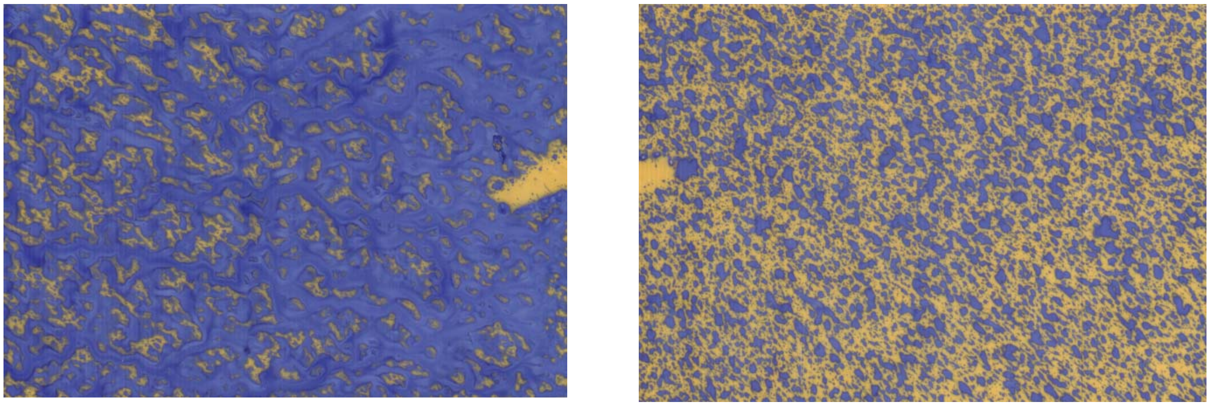
In the second year of Test 1, no infestation of crabapple trees was detected in Nursery #1. In Nursery #2, a Japanese beetle infestation was detected in weeping cherries, leafhoppers in red maples, spider mites in crabapple trees, and no insect infestation was detected in katsura trees. In Nursery #3, spider mite infestations were found in serviceberries.

Comparisons of insect infestations between half- and full-rate applications in the second year trial of these three nurseries are reported in Table 3. In both full- and half-rate treatments in Nursery #2, 14% of the leaves of weeping cherries were rated as 1 for Japanese beetle infestation. In contrast, the 13% of the leaves of red maples that rated as 1 in Nursery #2 only occurred in the second year trial. Regardless of treatment, the other plant species all rated as 0.

Table 2. Insect infestations on nursery trees treated with half- and full-rate pesticide applications in the first year trial for Test 1. Standard deviations are in parentheses.

Nursery	Tree species	Insects detected	Spray rate	% leaves infested at six rating levels[z] 0	1	2	3	4	5
#1	Crabapple	Aphid	Full	100 (0)	0	0	0	0	0
			Half	99 (2)	1	0	0	0	0
#2	Weeping cherry	Japanese beetle	Full	50 (7)	0	0	42	8	0
			Half	86 (10)	9 (12)	3 (3)	0 (0)	3 (7)	0
#2	Red maple	Leafhopper	Full	86 (14)	0	9 (12)	6 (14)	0	0
			Half	95 (7)	5 (7)	0	0	0	0
#2	Crabapple	Spider mite	Full	99 (1)	1 (1)	0	0	0	0
			Half	100 (0)	0	0	0	0	0
#2	Katsura	None	Full	100 (0)	0	0	0	0	0
			Half	100 (0)	0	0	0	0	0
#3	Serviceberry	Spider mite	Full	95 (6)	5 (6)	0	0	0	0
			Half	89 (6)	11 (6)	0	0	0	0
#2[y]	Red maple	Leaf hopper	Zero	0	0	0	100 (0)	0	0

[z]Rating level 0 represents no infestation, rating level 5 represents defoliation due to severe infestation and complete defoliation.
[y]A 0.1 ha control plot without any spray treatments.



(a) Full-rate application **(b) Half-rate application**

Fig. 4. Examples of typical spray deposition and coverage on yellow water sensitive papers inside canopies with (a) full-rate application and (b) half-rate application

The incidences of diseases on nursery trees with full- and half-rate application treatments for Test 1 in the first year trial are reported in Table 4. In Nursery #1, 20% of the leaves in both the full- and half-rate fields had rating levels of 1, 2 and 3 for apple scab (*Venturia inaequalis*) in the crabapples. Tar spot (*Rhytisma*) was detected in red maples, apple scab (*Venturia inaequalis*) in crabapples, and no diseases in weeping cherries and katsura trees in Nursery #2. In Nursery #3, powdery mildew (*Podosphaera clandestina*) was found in serviceberries. Over 92% of the leaves remained disease free in Nurseries #2 and #3 treated with either the full- or half-rate treatment.

For the second year of Test 1, apple scab and powdery mildew were detected in crabapples in Nursery #1 (Table 5). Leaf spot and shot hole were detected in red maples, shot hole in crabapples, but no diseases in katsuras in Nursery #2. Three percent of the leaves of serviceberries in Nursery #3 were rated as 1 for powdery mildew infection. Unexpectedly, the disease damage to plants treated with full-rates was apparently higher than the damage to plants in half-rate fields (Table 5). However, all damages were minimal, and rated as 1 or 2.

Among nursery crops, crabapples are the most susceptible to diseases. However, still more than 92% of the crabapple leaves were disease free after the treatment was switched to a half-rate application. An observation that some trees treated with the half-rate applications had greener and more foliage in the summer and kept the foliage one to two weeks longer in the autumn than trees with full-rate treatments suggested phytotoxicity with the full-rate applications.

Table 3. Insect infestations on nursery trees treated with half- and full-rate pesticide applications in the second year trial for Test 1. Standard deviations are in parentheses.

Nursery	Tree species	Insects detected	Spray rate	% leaves infested at six rating levels[z]					
				0	1	2	3	4	5
#1	Crabapple	None	Full	100 (0)	0	0	0	0	0
			Half	100 (0)	0	0	0	0	0
#2	Weeping cherry	Japanese beetle	Full	86 (27)	14 (27)	0	0	0	0
			Half	86 (13)	14 (13)	0	0	0	0
#2	Red maple	Leafhopper	Full	99 (1)	1 (1)	0	0	0	0
			Half	87 (19)	13 (19)	0	0	0	0
#2	Crabapple	Spider mite	Full	100 (0)	0	0	0	0	0
			Half	99 (2)	1 (2)	0	0	0	0
#2	Katsura	None	Full	100 (0)	0	0	0	0	0
			Half	100 (0)	0	0	0	0	0
#3	Serviceberry	Spider mite	Full						
			Half	100 (0)	0	0	0	0	0
#2[y]	Crabapple	None	Half	100 (0)	0	0	0	0	0

[z]Rating level 0 represents no infestation, rating level 5 represents severe pest infestation and complete defoliation.
[y]Third year of spray treatments.

Table 4. **Disease incidence on nursery trees treated with full- and half-rate pesticide applications in the first year trial for Test 1. Standard deviations are in parentheses.**

Nursery	Tree species	Diseases detected	Spray rate	% diseased leaves at six rating levels[z] 0	1	2	3	4	5
#1	Crabapple	Apple scab	Full	80 (3)	12 (2)	8 (2)	0	0	0
			Half	80 (12)	10 (7)	9 (8)	1 (2)	0	0
#2	Weeping cherry	None	Full	100 (0)	0	0	0	0	0
			Half	100 (0)	0	0	0	0	0
#2	Red maple	Tar spot	Full	97 (3)	3 (3)	0	0	0	0
			Half	97 (3)	3 (3)	0	0	0	0
#2	Crabapple	Apple scab	Full	93 (13)	7 (13)	0	0	0	0
			Half	99 (3)	1 (3)	0	0	0	0
#2	Katsura	None	Full	100 (0)	0	0	0	0	0
			Half	100 (0)	0	0	0	0	0
#3	Serviceberry	Powdery mildew	Full	92 (6)	8 (6)	0	0	0	0
			Half	100 (0)	0	0	0	0	0

[z]Rating level 0 represents no disease infection, rating level 5 represents defoliation due to severe disease infection

Most importantly, all growers who participated in Test 1 with the half-rate application treatment were satisfied with the final quality of their crops. Because of these results and the economic benefits with the half-rate application, the spray application treatment for Nursery #3 was changed from full- to half-rate in the second and subsequent years. Nurseries #1 and #2 also switched to the half-rate application in their production fields in the third and subsequent years. These nurseries had a long history of producing high quality nursery plants with a high quality of spray applications.

Test 2. Results of aphid control at the half-rate and full-rate [650 and 1,400 liters·ha^{-1} (69 and 155 gal·A^{-1}), respectively] with Talstar® spray applications in Test 2 are presented in Table 6. Generally, more aphid infestation was observed on leaves of plants in the plots to be treated with the half-rate application than on leaves of plants in plots to be treated with the full-rate application. The infestation by 10 or more aphid ranged from 0 to 57.8% of the leaves in the full-rate treatment and ranged from 32.2 to 74.4% of the leaves in the half-rate treatment. Three days after spraying, number of live aphids per 30 leaves ranged from 0 to 3.3 in the full-rate zone and ranged from 1.1 to 6.7 in the half-rate zone. Complete eradication was achieved 12 days after spray application. Therefore, the reduced rate application was equally effective as the label recommended full-rate application for control of aphids.

State inspector survey. Table 7 summarizes state inspectors surveys of the total number of arthropod species detect-

Table 5. **Disease incidence on nursery trees treated with full- and half-rate pesticide applications in the second year trial for Test 1. Standard deviations are in parentheses.**

Nursery	Tree species	Diseases detected	Spray rate	% diseased leaves at six rating levels[z] 0	1	2	3	4	5
#1	Crabapple	Apple scab and	Full	83 (5)	12 (9)	5 (5)	0	0	0
		Powdery mildew	Half	90 (10)	6 (4)	4 (8)	0	0	0
#2	Weeping cherry	Shot hole	Full	57 (30)	42 (32)	1 (3)	0	0	0
			Half	93 (12)	7 (12)	0	0	0	0
#2	Red maple	Leaf spot and	Full	83 (11)	17 (11)	0	0	0	0
		Shot hole	Half	99 (1)	1 (1)	0	0	0	0
#2	Crabapple	Shot hole	Full	62 (10)	38 (10)	0	0	0	0
			Half	100 (0)	0	0	0	0	0
#2	Katsura	None	Full	100 (0)	0	0	0	0	0
			Half	100 (0)	0	0	0	0	0
#3	Serviceberry	Powdery mildew	Full	Switched to half rate					
			Half	97 (3)	3 (3)	0	0	0	0

[z]Rating level = 0 represents no disease infection, rating level = 5 represents defoliation due to severe disease infection.

Table 6. Comparison of half- and full-rate spray applications for aphid control on birch trees in Test 2. Standard deviations are in parentheses.

Row #	Application rates (liters·ha^{-1})	Before spray: % leaves infested by ≥10 aphids	Mean number of live aphids per 30 leaves at days after spraying: 3 days	12 days
1	1400	0.0 (0)	0.0	0.0
2	1400	6.7 (11.5)	0.0 (0.0)	0.0
3	1400	38.9 (24.1)	1.1 (1.9)	0.0
4	1400	57.8 (15.4)	1.1 (1.9)	0.0
5	1400	52.2 (17.1)	3.3 (3.3)	0.0
6	650	62.2 (34.2)	2.2 (1.9)	0.0
7	650	74.4 (13.5)	6.7 (5.8)	0.0
8	650	32.2 (15.0)	2.2 (3.8)	0.0
9	650	46.7 (8.8)	1.1 (1.9)	0.0

ed, total number of plant varieties or species infested, and the number of plant varieties or species that had light, moderate or severe infestations for the half- and full-rate applications in two nursery fields from 2005 to 2010. Because these plants were in several locations and infested at different levels, the number of infested plants was not the same as the number of plants that had light, moderate and severe infestations. In the first field, 20 species of arthropods were detected in plants treated with the full-rate application in 2005 and 17 in 2006. In both years, the arthropod infestations occurred in 18 out of 2,800 plant varieties and species and they were light, moderate or severe. With the half-rate application in the first field, the number of species of arthropods detected was 14, 9, 8 and 12 in 2007, 2008, 2009 and 2010, respectively. Also, the numbers of plant varieties or species that had light, moderate or severe infestations were 16, 12, 11 and 9 in these four years, respectively. All infestations occurred in very small areas and some on just a few trees. These results suggest that the half-rate application was comparable to the full-rate application.

In the second field, insect control with the half-rate application was also comparable to that with the full-rate application (Table 7). The total number of insect species detected was 27 (average 13.5) in 2006 and 2007 when the full rate was used and the total was 40 (average 13.3) in 2008, 2009 and 2010 when the half rate was used. The annual average number of plant varieties or species infested in the half- and full-rate applications averaged 15.7 and 15.5, respectively. The levels of plant damage were similar to those in the first field. All infestations also occurred in very small areas, some were on just a few trees.

The disease incidence with the half-rate application (Table 8) followed the same trend as the incidence of insect infestations. That is, the number of diseases and the number of plant varieties or species with the half-rate application in a growing season was not greater than those with the full-rate application. For example, in 2005 and 2006 when the full-rate application was practiced in nursery field #1, average 13.5 diseases were detected in average 32 varieties and the incidences of disease were light, moderate or severe. In the subsequent four years when the half-rate application was practiced, the incidences of average 8.5 diseases in average 17.3 varieties were light, moderate or severe. In the second field, average 8 diseases in the average 10 plant varieties or species were found for the full-rate application while average 3.7 diseases in the average 5.7 plant varieties and species were found for the half-rate application. Also, the incidence of these diseases occurred in very small areas, some on just a few trees.

Figure 5 depicts the average numbers of insects or diseases identified (Fig. 5a) and the average numbers of plant varieties or species infested or infected (Fig. 5b) in the full-rate and half-rate application practices in the first two and subsequent four years in two nursery fields, respectively. The numbers

Table 7. State inspector surveys from 2005 to 2010 for arthropod infestations in two nursery fields with half- and full-rate applications.

Nursery field	Area (ha)	Year	Spray rate	Insect species detected	No. of plant varieties or species infested at three levels: Light	Moderate	Severe	Total infested plants[z]
#1	152	2005	Full	20	18	4	10	18
#1	154	2006	Full	17	13	8	3	22
#1	162	2007	Half	14	10	3	5	16
#1	168	2008	Half	9	12	1	0	12
#1	171	2009	Half	8	8	3	1	11
#1	171	2010	Half	12	6	4	2	9
#2	119	2006	Full	10	11	3	1	13
#2	120	2007	Full	17	20	5	1	18
#2	117	2008	Half	18	24	3	0	19
#2	124	2009	Half	11	15	4	1	14
#2	124	2010	Half	11	10	3	1	14

[z]Total number of plant varieties or species infested by insects.

Table 8. State inspector surveys from 2005 to 2010 for disease incidence in two nursery fields with half- and full-rate applications.

Nursery field	Area (ha)	Year	Application rate	Disease types detected	No. of plant varieties or species infected at three levels			Total infected plants[z]
					Light	Moderate	Severe	
#1	152	2005	Full	15	31	9	6	41
#1	154	2006	Full	11	4	14	6	23
#1	162	2007	Half	6	4	3	5	12
#1	168	2008	Half	8	14	2	9	24
#1	171	2009	Half	8	16	2	4	21
#1	171	2010	Half	12	6	5	1	12
#2	119	2006	Full	7	2	3	3	8
#2	120	2007	Full	9	0	9	3	12
#2	117	2008	Half	5	3	3	1	7
#2	124	2009	Half	2	4	0	0	4
#2	124	2010	Half	4	4	2	1	6

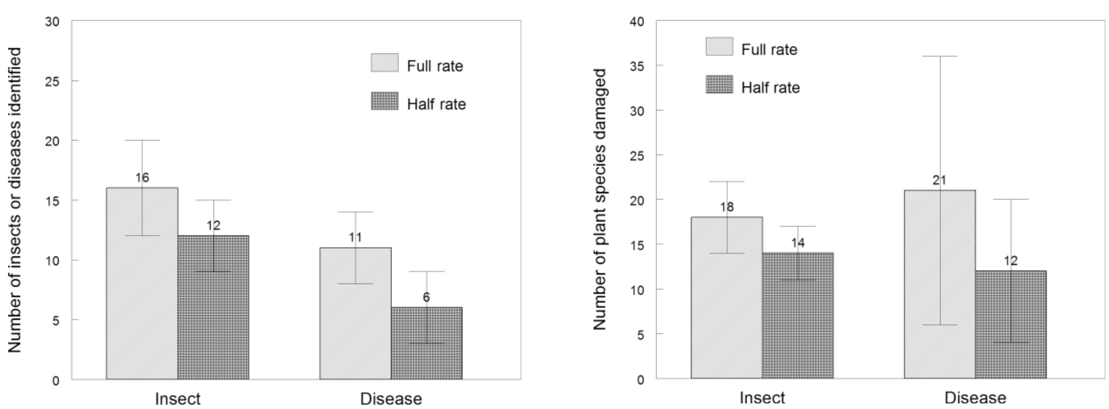
[z]Total number of diseased plant varieties or species.

of insects or diseases corresponded to the average number of plant varieties or species that had light, moderate or severe damages. The average numbers of insect and disease species detected for the full-rate application were 16 and 11 respectively while they were 12 and 6 for the half-rate application. Similarly, the average numbers of plant species infested by insects and infected by diseases for the full-rate application were 18 and 21 respectively while they were 14 and 12 for the half-rate application.

Generally, if more chemicals were applied per unit area one would expect better control of insect pests and diseases. Contrary to this expectation, this study demonstrated that control of insect pests and diseases provided by a half-rate pesticide application was comparable to that of a full-rate application. However, since this study was a large scale field demonstration of this hypothesis, the experimental design was not rigorous and was limited by the constraints of potential losses to the participating growers. Furthermore, many variables affect pest and disease control. For example, what interaction, if any, did the half-rate applications have on beneficial insects to control of insect pests? Or, what is the consequence of a half-rate application on the development of pest resistance to the chemicals?

Development of resistance to pesticide by the targeted organism has not been well-documented and threshold of dosages to create the resistance for specific organism has not been defined. It has been a concern that use of less than the labeled rate may contribute to selection for resistance. However, it is just as likely that the selection for resistant pest populations would arise from poor spray application procedures which allows for pest escapes. Consequently, greater amount of spray is recommended to compensate for the inefficiency. Spray application efficiency, which is the objective of this research, is a better criterion to judge the efficacy of pest control than is the amount of pesticide used.

A major impediment to the simplification and optimization of pesticide spray applications in nurseries is the inadequate quantification of dosages for current spray parameters. For example, the response relationships between the recommended and the required dosage for control of a particular level of insects or diseases are unknown. Also unknown is the effect of the recommended dosage on the deposition and coverage outcomes after spray application. Unfortunately, the only guidelines growers have for the presumed effective dosage rates for control of specific insects or diseases are the labeled rates. However, label rates currently do not address



(a) Insect and disease survey **(b) Plant survey**

Fig. 5. Average number of insects or diseases identified (a) and average number of plant varieties and species that had any light, moderate or severe damage (b) for half- and full-rate applications in two commercial fields surveyed by the State inspectors for six growing seasons.

the variability of crop density, the plant canopy shapes and sizes, the physical-chemical properties of spray mixtures, the amount of spray retention on crops, and the efficiency and uniformity of spray applications by different sprayers. The consequence of these omissions is that targeted and non-targeted areas are over sprayed, resulting in very low application efficiency. Despite different production practices, participating growers in these nurseries achieved comparable levels of pest and disease control with the half-rate application protocol. These results have encouraged other nurseries to consider this spray application approach. However, the minimal amount of pesticide required for adequate pest control is still undetermined but it is a necessary prerequisite to benefit growers and the environment.

In summary, this study demonstrated that the half-rate application of pesticides for pest and disease control was comparable to a full-rate application. Additionally, less phytotoxicity was observed on trees treated with half-rate applications.

Although the experiments in these investigations were not rigorous, repeated confirmation that the half-rate treatment was comparable to the full-rate treatment for the control of pests and diseases over time and different nursery locations. This body of evidence implied that with quality spray coverage applications, incorporation of prudent timing, appropriate equipment and chemicals, and an understanding of the mechanisms of chemical action, life cycles of pests and disease processes, current recommendations of pesticide dosages on labels exceed the threshold for what is required for economical insect and disease control.

Therefore, to establish the confidence for growers in use of the reduced rate method, a small acreage was suggested for trial in the first year. A larger area was then expanded in the second year and further expanded in the third year. After successful trials for three years, all production fields were recommended for the change to the reduced pesticide rates. Nurseries practiced the reduced application rate strategy in Ohio, Kentucky, Tennessee and Oregon during past several years reported satisfactory effectiveness of insect and disease controls.

Literature Cited

1. Derksen, R.C., C.R. Krause, R.D. Fox, and R.D. Brazee. 2004. Spray delivery to nursery trees by air curtain and axial fan orchard sprayers. J. Environ. Hort. 22:17–22.

2. Fox, R.D., D.L. Reichard, R.D. Brazee, C.R. Krause, and F.R. Hall. 1993. Downwind residue from air spraying a semi-dwarf apple orchard. Transactions of the ASAE 36:333–340.

3. Furness, G.O and W.V. Pinczewski. 1985. A comparison of the spray distribution obtained from sprayers with converging and diverging airjets with low volume air assisted spraying on citrus and grapevines. J. Agric. Eng. Res. 32:291–310.

4. Herrington, P.J., H.R. Mapother, and A. Stringer. 1981. Spray retention and distribution on apple trees. Pesticide Sci. 12:515–520.

5. Hislop, E.C. 1991. Review of air assisted spraying. *In*: Air-Assisted Spraying in Crop Production, p 3–14. A. Lavers, P. Herrington, and E.S.E. Southcombe, eds. BCPC Monograph No. 46. Alton, Hampshire, U.K.: BCPC Publications.

6. Holownicki, R., G. Doruchowski, A. Godyn, and W. Swiechowski. 2000. Variation of spray deposit and loss with air-jet directions applied in orchards. J. Agric. Eng. Res. 77:129–136.

7. Jerardo, A. 2007. Floriculture and nursery crops yearbook/FLO-2007/September 2007. Date accessed: July 15, 2010. http://www.ers.usda.gov/Publications/Flo/2007/09Sep/FLO2007.pdf

8. Krause, C.R., H. Zhu, R.D. Fox, R.D. Brazee, R.C. Derksen, L.E. Horst, and R.H. Zondag. 2004. Detection and quantification of nursery spray penetration and off-target loss with electron beam and conductivity analysis. Trans. ASAE 47:375–384.

9. Peterson, D.L. and H.W. Hogmire. 1994. Tunnel sprayer for dwarf fruit trees. Trans. ASAE 37:709–715.

10. Reichard, D.L., H.J. Retzer, L.A. Liljedahl, and F.R. Hall. 1977. Spray droplet size distributions delivered by air blast orchard sprayers. Trans. ASAE 20:232–237, 242.

11. Salyani, M. 2000. Optimization of deposition efficiency for airblast sprayers. Trans. ASAE 43:247–253.

12. Travis, J.W., W.A. Skroch, and T.B. Sutton. 1987. Effects of travel speed, application volume, and nozzle arrangement on deposition of pesticides in apple trees. Plant Disease 71:606–612.

13. Walklate, P.J., G.M. Richardson, J.V. Cross, and R.A. Murray. 2000. Relationship between orchard tree crop structure and performance characteristics of an axial fan sprayer. *In*: Aspects of Applied Biology 57: Pesticide Application, p 285–292. Wellesbourne, Warwick, U.K.: Association of Applied Biologists.

14. Zhu, H., R.C. Derksen, H. Guler, C.R. Krause, R.H. Zondag, and H.E. Ozkan. 2006. Foliar deposition and off-target loss with different spray techniques in nursery applications. Transactions of the ASABE, 49:325–334.

15. Zhu, H., R.H. Zondag, R.C. Derksen, M. Reding, and C.R. Krause. 2008. Influence of spray volume on spray deposition and coverage within nursery trees. J. Environ. Hort. 26:51–57.