Control of Insects and Diseases with Intelligent Variable-rate Sprayers in Ornamental Nurseries[1]

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Abstract

Intelligent spray technology can reduce pesticide use and safeguard the environment; however, its ability to effectively control insects and disease must be validated before its adoption by growers. Comparative tests for two different laser-guided variable-rate intelligent sprayers and the same sprayers with conventional constant-rate mode were conducted to control pests at two ornamental nurseries in two growing seasons in Ohio. Crabapple [*Malus* 'Sutyzam' (Sugar Tyme®), *M. sargentii*], apple (*Malus pumila*), maple [*Acer ×freemanii* 'Jeffersred' (Autumn Blaze®), *A. rubrum* 'Franksred' (Red Sunset®) and *A. rubrum*], birch (*Betula nigra* and *Betula populifolia* 'Whitespire'), London planetree (*Platanus ×acerifolia* 'Bloodgood') and dogwood (*Cornus florida*) were used as the test plants. Intelligent spray technology reduced pesticide use by 56.1% and 51.8% on average at the two nurseries, respectively. Compared to conventional air-assisted sprayers, severity of scab on apple trees and powdery mildew in dogwood was reduced on intelligent spray-treated plants at one nursery, and there were equal or fewer leafhoppers in maple trees and aphids in birch trees when sprayed using intelligent spray technology at both nurseries. These results suggest that intelligent, variable-rate sprayers achieve equivalent or greater insect and disease control in ornamental tree nurseries compared to conventional, constant-rate sprayers.

Index words: aphid, apple scab, environmental protection, leafhopper, precision spray, powdery mildew, sustainable.

Species used in this study: apple (*Malus pumila* Mill), birches (*Betula nigra* L, *Betula populifolia* Marsh. 'Whitespire'), crabapples [*Malus* 'Sutyzam' (Sugar Tyme®), *M. sargentii* Rehder], dogwood (*Cornus florida* L.), maples [*Acer ×freemanii* E. Murray 'Jeffersred' (Autumn Blaze®), *A. rubrum* L. 'Franksred'(Red Sunset®) and *A. rubrum* L.], London planetree [*Platanus ×acerifolia* (Ait.) Willd. 'Bloodgood'].

Significance to the Horticulture Industry

Compared to sprayers equipped with intelligent variable-rate technology, conventional constant-rate sprayers often use more pesticide to achieve insect and disease control in ornamental nurseries. Recently developed intelligent, variable-rate sprayers deliver sufficient pesticide volume to tree canopies with varying size and a range of canopy characteristics while reducing the amount reaching the ground and air, thereby reducing pesticide and operational costs as well as any adverse impact to the environment. However, there have been very few reports about the efficiency of the intelligent sprayers for the control of insect and disease pests. This research indicates that the intelligent sprayers are equally or more effective for control of insect and disease pests in ornamental tree nurseries. Thus, intelligent spray technology provides a highly efficient, low cost, and environment- and worker-friendly pesticide spray technology for the ornamental nursery industry.

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Introduction

In the ornamental nursery industry, it is essential for the producers to manage many different insects and diseases (Braman et al. 2015, Mizell and Short 2018, Schuh and Mote 1948). These management techniques include removing dead or unhealthy plants and leaf litter, pruning out infected sections, growing pest-resistant selections, trapping and monitoring insects and diseases, and applying pesticides (LeBude et al. 2012, Mizell and Short 2018). For ornamental plants to meet market requirements, pesticide applications to ensure healthy and unblemished plants are critical (Cloyd 2009, Glasgow 1999, Zhu et al. 2011a). Therefore, 1.3 million kg (2.8 million lb) of pesticide active ingredient is used every year by the greenhouse and nursery industries in the United States (Hudson et al. 1996).

Radial air-assisted sprayers are the most commonly used application equipment for ornamental nurseries to control insects and diseases (Zhu et al. 2017). However, conventional sprayers deliver pesticides at a constant rate regardless of plant growth stage or crop density, which contributes to low application efficiency. Also, spray applicators usually configure and operate sprayers to apply pesticides to the entire field and to the whole plant regardless of the plant size or shape, or pest location (i.e., trunk, foliage), resulting in plants that are often under-sprayed or over-sprayed (Zhu et al. 2008). At the same time, a significant portion of the sprayed pesticide is delivered to the ground and air (Zhu et al. 2006b), wasting pesticide and contaminating the environment, which increases production costs and can adversely affect the health of spray applicators and people in close proximity to the nursery. Many spray methods have been evaluated to

Fig. 1. **Locations of the two experimental sites: Willoway Nurseries, Inc (red star) and Herman Losely & Son, Inc (red circle) in Ohio, USA.**

reduce pesticide use in nurseries (Derksen et al. 2004, Zhu et al. 2006a, 2006b, 2011a, 2011b).

To resolve the problems associated with inefficiency of the conventional sprayers in nursery applications, a variable-rate intelligent sprayer for nursery and fruit tree crops was developed (Chen et al. 2012, Shen et al. 2017). The sprayer is able to adjust application rates by controlling the spray output of each nozzle based on the presence, structure and foliage density of plants and sprayer travel speed. It discharges the appropriate pesticide volume in real time in response to the crop characteristics. Chen et al. (2013) reported that the intelligent sprayer reduced the spray volume by 47% to 73% compared to a conventional constant-rate sprayer in an apple orchard experiment at three different phenological stages of apple (*Malus domestica* Borkh). Zhu et al. (2017) reported no difference in spray deposition and coverage compared to a conventional constant-rate sprayer at 24.0 L·min^{-1} (6.3 gal·min^{-1}) in multiple-row nursery trees 'Sterling' silver linden (*Tilia tomentosa* Moench) and Northern red oak (*Quercus rubra* L.) when intelligent variable-rate sprayer discharged a spray mixture of water and a fluorescent tracer.

The hypothesis of this research was that the use of intelligent sprayers, which can substantially reduce pesticide application volume and environmental contamination, would be an effective approach to control insect and disease pests during commercial nursery production. The objective of this study was to evaluate insect and disease control in multiple-row blocks in two ornamental nurseries using intelligent, variable rate pesticide applications.

Materials and Methods

Nursery test plots. Field studies were conducted in two consecutive growing seasons in 2017 and 2018 at two commercial nurseries (Fig. 1). One was Willoway Nurseries, Inc. (latitude: 41.427065; longitude: -82.049974), located in Avon, Ohio, and the other was Herman Losely & Son, Inc. (latitude: 41.755844; longitude: -81.161971), located in Perry, Ohio. At Willoway Nurseries, birch, crabapple, London planetree, and maple trees were used, and at Herman Losely & Son, apple, birch, dogwood, and maple trees were selected as the test plants.

At the Willoway Nurseries site, all plants for this study were three-years-old and grown in a "pot in pot" multiple-row production system (Fig. 2 A). The sizes of the treatment plots were 26.2 × 7.3 m (86.0 × 24.0 ft) for London planetree, 42.1 × 6.1 m (138 × 20.0 ft) for crabapple, 56.5 × 7.9 m (185 × 26.0 ft) for birch, to 55.6 × 8.2 m (182 × 27.0 ft) for maple. Experimental design and test trees are described in Table 1. Crabapple trees grown in 50.6 L (13.4 gal) containers were arranged in 6 rows with 1.2 m (4.0 ft) spacing between two rows and 1.1 m (3.5 ft) spacing between two trees. Average tree height and width of crabapple in Aug. 2018 were 2.2 m (7.1 ft) and 0.85 m (2.8 ft), respectively. Maple trees grown in 50.6 L (13.4 gal) containers were arranged in 8 rows with 1.2 m (3.9 ft) spacing between two rows and 1.1 m (3.5 ft) spacing between two trees. Tree height of maple was an average of 2.5 m (8.2 ft) and average width of 0.80 m (2.6 ft) in Aug. 2018. Birch trees grown in 95.2 L (25.2 gal) containers were arranged in 6 rows with 1.6 m (5.2 ft) spacing between two rows and 1.3 m (4.4 ft) spacing between two trees. Tree height of birch was an average of 4.7 m (15.3 ft) and average width of 1.3 m (4.4 ft) in Aug.

A B

Fig. 2. **Maple plants were grown in a "pot in pot" multiple-row production system at Willoway Nurseries (A) and grown directly on land at Herman Losely & Son (B).**

Table 1. Experimental fields, test plants, and pests of study in a pot-in-pot production system at Willoway Nurseries.

Plant	Number of rows	Plant height[z] (m)	Row spacing (m)	Tree spacing (m)	Size of container (L)	Pest of study
Crabapple *Malus sargentii* (2017) *M.* Sugar Tyme® (2018)	6	2.2	1.2	1.1	50.6	Scab
Maple *Acer rubrum* Red Sunset® (2017) *A.* ×*freemanii* Autumn Blaze® (2018)	8	2.5	1.2	1.1	50.6	Leafhopper
Birch *Betula populifolia* 'Whitespire' (2017) *B. nigra* (2018)	6	4.7	1.6	1.3	95.2	Aphid
London Planetree *Platanus* ×acerifolia 'Bloodgood' (2018)	8	2.9	1.0	1.1	50.6	Powdery mildew

[z]Measured in August 2018.

2018. London planetree grown in 50.6 L (13.4 gal) containers were arranged in 8 rows with 1.0 m (3.4 ft) spacing between two rows and 1.1 m (3.5 ft) spacing between two trees. Height of London planetree was an average of 2.9 m (9.6 ft) and average width of 1.1 m (3.5 ft) in Aug. 2018. Because the plants for the 2017 experiment were removed after the growing season, new plants were chosen for the 2018 experiment. Thus, the species of crabapple, maple and birch for this study were different in 2017 and 2018. Also, the height of plants for the 2017 experiment was not measured, and the experiment in London planetree was conducted only in 2018.

At the Herman Losely & Son site, all plants were grown directly in the field and arranged in 4 rows with a larger spacing between the middle of two rows as a drive row for equipment to access trees for pesticide application (Fig. 2 B). The experiments were conducted in two consecutive growing seasons with the same plants. Apple trees were two-years-old, and maple, birch and dogwood trees were three-years-old in 2017. The sizes of the treatment plots were 50.5 × 10.1 m (166 × 33.0 ft) for dogwood, 42.0 × 12.2 m (138 × 40.0 ft) for apple, 69.0 ×12.8 m (226 × 42.0 ft) for birch and 74.3 × 12.2 m (244 × 40.0 ft) for maple. Experiment design and test trees are described in Table 2. Apple trees were grown in 2 rows in a block with 4 rows which had two rows of apple trees alternating with two rows of pear trees that were not in the study. Spacing on both sides between rows was 2.4 m (8.0 ft), and spacing between trees was 1.8 m (6.0 ft), with 3.7 m (12.0 ft) spacing between the middle of two rows. Tree height of apple was an average of 2.7 m (9.0 ft) in Aug. 2018. Maple trees were grown in 4 rows with 2.4 m (8.0 ft) spacing between two rows on both sides and 3.7 m (12.0 ft) spacing between the middle of two rows. Spacing between two trees was 1.9 m (6.2 ft). Tree height of maple was an average of 3.0 m (10.0 ft) in Aug. 2018. Birch trees were grown in 4 rows with 2.4 m (8.0 ft) spacing between two rows on both sides and 4.0 m (13.0 ft) spacing between the middle of two rows. Spacing between trees was 2.0 m (6.5 ft), and tree height was an average of 4.9 m (16.0 ft) in Aug. 2018. Dogwood trees were grown in 4 rows with 2.3 m (7.5 ft) spacing between two rows on both sides and 2.7 m (9.0 ft) spacing between the middle of two rows. Spacing between trees was 1.5 m (5.0 ft), and tree height was an average of 2.5 m (8.1 ft) in Aug. 2018.

Apple scab (*Venturia inaequalis* Cooke) is a severe fungal disease of crabapple and apple (MacHardy 1996). This disease attacks plant leaves, buds and fruits (Fig. 3) and occurs globally (Gauthier 2018). *Venturia inaequalis* usually overwinters in fallen leaves. In spring, ascospores are sexually produced in asci in the fruiting bodies (pseudothecia) of the infected fallen leaves from the previous growing season. When it is warm and trees are wet, the ascospores in the asci are released into the air and spread. Throughout the growing season, conidia are asexually developed on the surfaces of the infected leaves and dispersed to other leaves. For the ornamental nursery industry, scab infection can cause substantial aesthetic damage by causing leaves to turn yellow with unsightly

Table 2. Experimental fields, test plants, and pests of study at Herman Losely & Son.

Plant	Plant age (year)	Plant height[z] (m)	Row spacing (m)	Tree spacing (m)	Spacing of drive row (m)	Pest of study
Apple *Malus pumila*	2-3	2.7	2.4	1.8	3.7	Scab
Maple *Acer rubrum*	3-4	3.0	2.4	1.9	3.7	Leafhopper
Birch *Betula nigra*	3-4	4.9	2.4	2.0	4.0	Aphid
Dogwood *Cornus florida*	3-4	2.5	2.3	1.5	2.7	Powdery mildew

[z]Measured in August 2018.

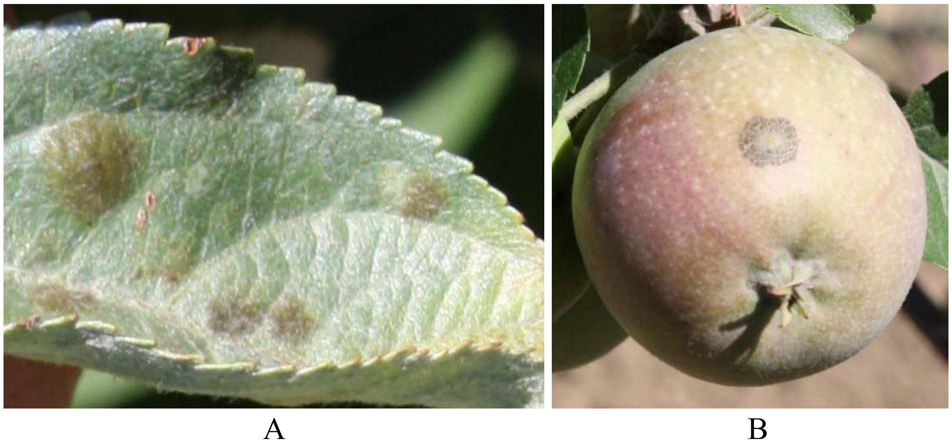

Fig. 3. An apple leaf (A) and an apple fruit (B) with symptoms of apple scab from Herman Losely & Son.

black spots and eventually drop, rendering infected trees less marketable.

Potato leafhopper (*Empoasca fabae* Harris) is a severe pest of maple trees in nursery in the Eastern US, especially when forage fields such as alfalfa are nearby and the hay is cut, which causes leafhoppers to move to maple trees for food (Frank et al. 2013, Smitley 2011). Adult potato leafhoppers are around 3 mm long, wedge-shaped, and pale green. Several generations may be produced in one year and can cause hopperburn on new growth (Fig. 4). Xylem-fastidious bacteria vectored by leafhoppers can transmit bacterial diseases in maple, resulting in high mortality risk (Center for Urban Ecology and Sustainability 2013).

Aphids are one of the insects feeding on birch in Ohio (Division of Forestry, Ohio Department of Natural Resources 2018a). Eight aphid species in 6 genera feed on river birch (*B. nigra*), the species of birch in this study in 2018 (Anonymous 2018). Aphids are usually 2 to 4 mm long, with a pear-shaped body with wings or wingless, and a soft body texture. Aphid eggs overwinter on the infested birch. In spring, the eggs hatch, and male and female aphids mature. In spring and summer, instead of laying eggs, females asexually give birth to live young. Thus, several generations may be produced quickly, leading to a rapid increase in population (Holsten and Schultz 2011).

Fig. 4. Maple shoots with symptoms of browning by leafhoppers at Herman Losely & Son.

Birch trees are susceptible to aphids that feed on the succulent tissues of newly growing leaves, buds, and developing stems (Fig. 5 A). The infected leaves become swollen, malformed and yellow. Although aphid infection usually does not cause the death of entire birch trees, it can result in the death of leaves and shoots (Holsten and Schultz 2011). In addition, when aphids feed on the leaves, they secrete a sticky substance, called honeydew, onto the surface of leaves, which often leads to the growth of the fungal disease sooty mold (Fig. 5 B).

Powdery mildew is a common foliage disease in ornamental plants such as dogwood (Fig. 6 A) (NRCS, USDA 2004, Division of Forestry, Ohio Department of Natural Resources 2018b, Witte et al. 2000) and London planetree (Fig. 6 B) (Blake et al. 2018, Moorman 2016). Dogwood powdery mildew is primarily caused by the fungus *Erysiphe pulchra* (Cooke & Peck) U. Braun & S. Takam. and *Phyllactinia guttata* (Wallr.:Fr.) Lev. (Mmbaga 2000), and London planetree powdery mildew is caused by *Erysiphe platani* (Howe) U. Braun & S. Takam (Ligoxigakis et al. 2015). Symptoms of powdery mildew may occur from late spring to autumn on new growth (Hartman 2008). This disease can cause substantial aesthetic damage and reduce the winter hardiness of plants (Witte et al. 2000).

Sprayer treatments. The sprayers tested were two different types of conventional air-assisted sprayers retrofitted with the same laser-guided intelligent spray control system (Fig. 7). At Willoway Nurseries, a custom-built vertical tower air-blast sprayer (Fig. 7 A) (Model SP22, George F. Ackerman Company, Curtice, Ohio) equipped with 9 hollow cone-nozzles on each side that applied 650 $L\cdot ha^{-1}$ (69.5 $gal\cdot acre^{-1}$) was tested. At Herman Losely & Son a radial air-blast sprayer (Fig. 7 B) (Model PAK-BLAST, Rears MFG, Co., Eugene, Oregon) equipped with 7 hollow-cone nozzles on each side that applied 520 $L\cdot ha^{-1}$ (55.6 $gal\cdot acre^{-1}$) was tested. The intelligent spray control system consisted of a laser scanning sensor (UTM-30LX, Hokuyo Automatic CO., LTD, Japan), a speed sensor (RVSIII Radar Velocity Sensor, DICKEY-john Corporation, Auburn, Illinois), a sophisticated automatic nozzle flow rate controller (Liu et al. 2014), an embedded

A B

Fig. 5. Aphids in a birch leaf from Herman Losely & Son (A) and fungal disease sooty mold in an aphid infected leaf from Willoway Nurseries (B).

computer with a touch screen (MXE-1005, Fanless Embedded Computer, ADLINK Technology Inc, Taiwan), and nozzles coupled with pulse width modulated flow control valves (Model DS55295-12, TeeJet Technologies, Springfield, Ilinios). Sprayers were tested by operating in automatic mode and manual mode. In the automatic mode, tree canopy presence, size, shape, leaf density, and tractor speed were sensed and used to calculate and apply the appropriate amount of pesticide in real-time. In the manual mode, the automatic control function was disabled, and all nozzles were continuously activated, discharging a constant application rate. The manual mode simulated a conventionally operated sprayer and served as the control. Sprayers were operated at 690 kPa (100 psi) pressure with a travel speed of 5.6 km h^{-1} (3.5 MPH). Each growing season, plants in test plots were sprayed 14 times at Willoway Nurseries and 2 to 4 times at Herman Losely & Son (Tables 3 and 4).

Pesticide use and pest control. Pesticide volume applied was recorded from the intelligent spray system monitor. Presence and number of potato leafhoppers in maple, aphids in birch, and severity of apple scab in apple and crabapple and severity of powdery mildew in London planetree and dogwood were monitored and recorded every 1 to 2 weeks during the growing season (Table 1 and 2). Individual trees were randomly selected at the beginning of the season and scouted for the remainder of season.

To monitor the population of potato leafhoppers, yellow sticky traps (3 in $\times$ 5 in, BASF Corporation, St. Louis, MO, USA) were secured inside maple canopies (Heinz et al. 1992, Potter and Spicer 1993). In each spray treatment plot, three yellow sticky traps were randomly placed, one in each of three maples trees at Willoway Nurseries, and six yellow sticky traps were randomly placed one in each of six maples trees at Herman Losely & Son. Leafhoppers were counted, and the traps were replaced. To monitor aphids in birch, five trees were randomly selected in each plot, and ten branches were randomly selected from each tree. Aphids in the selected branches were counted every 1 to 2 weeks. To assess apple scab severity in apple and crabapple and powdery mildew severity in London planetree and dogwood, seven trees were randomly selected from each plot, the proportion of total leaf area infected was observed and recorded, with severity scales divided into 10 levels from 0 to 5 with 0.5 increments.

A B

Fig. 6. Powdery mildew infection on dogwood leaves (A) at Herman Losely & Son and on London planetree leaves (B) in Lake County, Ohio.

Statistical analysis. The results were analyzed using a model that included sprayer mode as the independent variable. Comparisons of spray effects on the number of insect pests of leafhopper and aphid and diseases of scab and powdery mildew at an individual date were analyzed by paired *t*-tests using Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA). When the analysis generated a significant F value ($P \leq 0.05$) for treatments, different letters were marked after the means.

Results and Discussion

Pesticide use. At Willoway Nurseries, when in conventional mode, the sprayer applied 936, 654, 806, 390 L·ha^{-1} (100, 69.9, 86.2, 41.7 gal·A^{-1}) on average for the two growing seasons in crabapple, maple, birch and London planetree, respectively, while the corresponding application rates in intelligent mode were 289, 188, 467, 187 L·ha^{-1} (30.9, 20.1, 49.9, 20.0 gal·A^{-1}) (Table 5). The intelligent spray mode reduced pesticide use by 67.8% in crabapple, 71.9% in maple, 32.6% in birch on average for the two years and 52.1% in London planetree for the year it was included the study compared to the conventional spray mode. For all plants at the site, the intelligent sprayer reduced average pesticide use by 56.1%.

At Herman Losely and Son (Table 6), the conventional spray mode applied 470 L·ha^{-1} (50.3 gal·A^{-1}) to all crops, while the intelligent spray application rate was 186 L·ha^{-1} (19.9 gal·A^{-1}) for apple, 185 L·ha^{-1} (19.8 gal·A^{-1}) for maple, 242 L·ha^{-1} (25.9 gal·A^{-1}) for birch, and 296

A B

Fig. 7. Air-blast sprayers retrofitted with the intelligent spray system used for tests at Willoway Nurseries (A) and Herman Losely & Son (B). (A) custom-built, 3,407 L (900-gallon) tank capacity, vertical tower air-blast sprayer; (B) 379 L (100-gallon) tank capacity, redical air-blast sprayer.

$L{\cdot}ha^{-1}$ (31.6 $gal{\cdot}A^{-1}$) for dogwood. With the intelligent spray mode, pesticide volume was reduced 60.5%, 60.8%, 48.7% and 37.1% on average for the two years for apple, crabapple, birch, and dogwood, respectively, compared to the conventional spray mode. For all crops at this location, the intelligent spray mode reduced pesticide use by 51.8%.

Intelligent spray technology reduced pesticide use by more than 60% in crabapple, apple, and maple because these plants were relatively smaller in height and width with small canopies and were spaced widely, which is comparable with a spray reduction of 53% when compared with a constant, half rate (50 gal per acre) application to apples (Chen et al. 2013). However, intelligent spray technology only reduced pesticide volume an average of 32.6% when applied to birch at Willoway Nurseries. In three of the four experiments with birch, pesticide volume was reduced by 42.1 to 55.3%; however, in 2018, there was a 15.3% pesticide volume reduction. The more modest reduction in 2018 was likely because the birch trees were bigger in height and width, compared to the crabapple, maple and London planetree, had large canopies that overlapped, and were spaced more densely, leaving no empty space between plants (1.3 m) compared with 2.0 m between birch at Herman Losely & Son (Tables 1 and 2).

In another pot-in-pot nursery, intelligent spray technology reduced pesticide volume by about 30% in large #15 size oak (*Quercus* sp.) trees with little space between canopies, whereas the nursery-wide savings, which include a substantial portion of smaller plants, were approximately 50% (Fulcher, unpublished data). A sprayer retrofitted with

Table 3A. Pesticide application program at Willoway Nurseries in 2017.

Date	Pesticides in 379 L (100 gal) solution	Remark*
5/29/2017	Bifenthrin 0.47 L (16 oz), Banner Maxx 0.35 L (12 oz), Pylon 0.12 L (4 oz)	For crabapple & maple
5/29/2017	Astro 0.24 L (8 oz), Banner Maxx 0.35 L (12 oz), Timectin 0.09 L (3 oz)	For birch only
6/06/2017	Flagship 0.12 L (4 oz), Pageant 0.35 L (12 oz), Actuate 0.12 L (4 oz)	
6/12/2017	Altus 0.24 L (8 oz), Heritage 0.06 L (2 oz), Sanmite 0.12 L (4 oz)	
6/19/2017	Safari 0.35 L (12 oz), T-Methyl 0.71 L (24 oz), Shuttle 0.24 L (8 oz)	
6/26/2017	Astro 0.24 L (8 oz), Banner Maxx 0.35 L (12 oz), Timectin 0.47 L (16 oz)	
7/03/2017	Flagship 0.12 L (4 oz), Heritage 0.06 (2 oz), Magus 0.53 L (18 oz)	Captiva 0.71 L (24 oz) added
7/10/2017	Quasar 0.25 L (8.5 oz), T-Methyl 0.71 L (24 oz), Savate 0.12 L (4 oz)	
7/17/2017	Imacloprid 0.05 L (1.7 oz), Medallion 0.06 L (2 oz), Sanmite 0.12 L (4 oz)	
7/30/2017	Bifenthrin 0.47 L (16 oz), Fenstop 0.35 L (12 oz), Actuate 0.12 L (4 oz)	
8/05/2017	Safari 0.34 L (12 oz), Stature 0.18 L (6.12 oz), Savate 0.12 L (4 oz)	
8/15/2017	Astro 0.24 L (8 oz), Heritage 0.06 L (2 oz), Sultan 0.30 L (10 oz)	
8/26/2017	Discuss 0.74 L (25 oz), T-Methyl 0.71 L (24 oz), Savate 0.12 L (4 oz)	
9/09/2017	Flagship 0.12 L (4 oz), Heritage 0.06 L (2 oz), Actuate 0.12 L (4 oz)	
9/15/2017	Astro 0.24 L (8 oz), T-methyl 0.71 L (24 oz), Pylon 0.12 L (4 oz)	
9/23/2017	Flagship 0.12 L (4 oz), Fenstop 0.35 L (12 oz), Actuate 0.12 L (4 oz)	

*If not indicated, the test plants were crabapple, maple and birch.

Table 3B. Pesticide application program at Willoway Nurseries in 2018.

Date	Pesticides in 379 L (100 gal) solution	Remark*
5/24/2018	Discuss 0.74 L (25 oz), T-methyl 0.59 L (20 oz), Actuate 0.12 L (4 oz)	
6/03/2018	Safari 0.35 L (12 oz), Banner Maxx 0.25 L (12 oz), Savate 0.12 L (4 oz)	
6/7-11/2018	Quasar 0.25 L (8.5 oz), Compass 0.06 L (2 oz)	
6/16-19/2018	Flagship 0.12 L (4 oz), T-methyl 0.59 L (20 oz), Actuate 0.12 L (4 oz)	
6/24/2018	Discuss 0.74 L (25 oz), Pageant 0.35 L (12 oz), Magus 0.53 L (18 oz)	
7/01/2018	Upstar gold 0.59 L (20 oz), Stature 0.18 L (6.12 oz)	
7/7-8/2018	Astro 0.24 L (8 oz), Compass 0.06 L (2 oz), Shuttle 0.24 L (8 oz)	
7/14-17/2018	Discuss 0.74 L (25 oz), Heritage 0.06 L (2 oz), Sanmite 0.12 L (4 oz)	Last spray for birch
7/22/2018	Altus 0.24 L (8 oz), T-methyl 0.59 L (20 oz), Savate 0.12 L (4 oz)	
7/30/2018	Flagship 0.12 L (4 oz), Banner Maxx 0.35 L (12 oz), Magus 0.53 L (18 oz)	For crabapple only
8/05/2018	Flagship 0.012 L (4 oz), Segway 0.09 L (3 oz), Sultan 0.30 L (10 oz)	For maple and London planetree
8/26/2018	Timectin 0.24 L (8 oz), Pageant 0.35 L (12 oz)	For maple and London planetree
9/02/2018	Discuss 0.74 L (25 oz), T-methyl 0.59 L (20 oz), Savate 0.12 L (4 oz)	
9/06/2018	Quasar 0.25 L (8.5 oz), Compass 0.06 L (2 oz), Sultan 0.30 L (10 oz)	For maple and London planetree
9/22/2018	Quasar 0.25 L (8.5 oz), T-methyl 0.59 L (20 oz), Actuate 0.12 L (4 oz)	

*If not indicated, the test plants were crabapple, maple, birch and London planetree.

intelligent spray technology reduced season long pesticide use by 33% in large orchard-grown ‘Golden Delicious’ apples (*Malus domestica* Borkh) with a nearly contiguous canopy (Fulcher, unpublished data). Thus, in commercial nurseries, use of intelligent spray technology reduces pesticide volume even among large trees with limited gaps between canopies, but is of even greater benefit on young trees with a multi-year crop cycle due to the relatively wide spacing between trees.

Control of apple scab. Apple scab was not detected in crabapple trees at Willoway Nurseries in either the conventional or intelligent spray treatments during the two growing seasons. Severity of apple scab in apple trees at Herman Losely & Son is shown in Fig. 8. For all measurement dates during the 2017 growing season, there were no differences in apple scab between intelligent and conventional spray modes except for June 22, when apple scab increased during the intelligent spray treatment, whereas in 2018, apple scab decreased during the intelligent spray treatment for all individual dates after the first spray.

Table 4. Pesticide application program at Herman Losely & Son.

Plant	Date	Pesticide	Concentration Per 379 L (100 gal) solution
Apple	04/26/2017	Agri-mycin	0.91 kg (2 lb)
	05/09/2017	Agri-mycin	0.91 kg (2 lb)
	06/03/2017	Pageant	0.35 L (12 oz)
	07/17/2017	Pageant	0.35 L (12 oz)
	04/30/2018	Agri-mycin plus Pageant	0.91 kg (2 lb)
	05/17/2018	Agri-mycin plus Pageant	0.91 kg (2 lb)
	07/04/2018	Pageant	0.35 L (12 oz)
Maple	06/08/2017	Tristar plus Cohere	0.27 L (9 oz)
	06/28/2017	Flagship	0.24 L (8 oz)
	06/07/2018	Tristar plus Cohere	0.35 L (12 oz)
	07/02/2018	Altos	0.35 L (12 oz)
Birch	06/08/2017	Tristar plus Cohere	0.27 L (9 oz)
	06/28/2017	Flagship	0.24 L (8 oz)
	06/14/2018	Tristar plus Hyperactive	0.35 L (12 oz)
	07/02/2018	Altos	0.35 L (12 oz)
Dogwood	06/28/2017	Banner Maxx	0.24 L (8 oz)
	08/01/2017	Banner Maxx	0.24 L (8 oz)
	06/29/2018	Banner Maxx	0.24 L (8 oz)
	08/14/2018	Banner Maxx	0.24 L (8 oz)

Because crabapple trees at Willoway Nurseries were sprayed 14 times both growing seasons, it was reasonable that no apple scab was detected for either conventional or intelligent spray applications. At Herman Losely & Son, apple trees were sprayed only four times in 2017 and three times in 2018 (Fig. 8) and apple scab occurred during both growing seasons. Zhu et al. (2017) reported that spray deposition and spray coverage inside multiple-row nursery trees were almost the same when intelligent spray technology was used compared to a conventional sprayer and Fulcher et al. (2018) found neither droplet density or disease control were affected by tree position within a multi-row block.

Sufficient pesticide coverage provided by the intelligent sprayer could explain the lack of difference in disease severity of apple scab for intelligent and conventional spray applications during the 2017 growing season on the vast majority of dates. It is possible that the reduced fungicide volume in the intelligent-spray-treated plot allowed naturally occurring, non-pathogenic fungi to thrive and they competed on the leaf surface with the *Venturia* fungi. Thus, apple scab severity would be lower for the intelligent spray compared to a conventional spray in apple trees in 2018. However, leaves of trees in the intelligent spray treatment were observed to remain on trees one to two weeks longer in the fall than those in the conventional spray treatment. This was probably because leaves on trees in the conventional-spray-treated plots received excessive chemicals which caused phytotoxicity.

Control of potato leafhoppers. Average leafhopper numbers in sticky card traps in maple at Willoway Nurseries and Herman Losely & Son are shown in Table 7 and Fig. 9, respectively. There was no effect of sprayer mode on the number of leafhoppers trapped at Willoway Nurseries (Table 7) or Herman Losely & Son (Fig. 9) in 2017. However, in 2018 there was a decrease in the number of leafhoppers in sticky traps in plots treated with intelligent technology on two dates at Willoway Nurseries site and several dates at Herman Losely & Son. Because insecticides used for the tests were not specific to

Table 5. Effects of conventional (Con) and intelligent (Int) spray applications on pesticide use in 2017 and 2018 at Willoway Nurseries.

	Crabapple		Maple		Birch		London planetree	
	Con	Int	Con	Int	Con	Int	Con	Int
2017								
Ave use (L)	50.8	10.5	78.7	23.7	108.5	53.2	N/A	N/A
Area (ha)	0.05	0.05	0.09	0.09	0.08	0.08	N/A	N/A
Ave rate (L/ha)	1043	216	877	263	1244	623	N/A	N/A
Change		-79.3%		-70.0%		-49.9%		N/A
2018								
Ave use (L)	20.1	8.78	14.0	5.03	14.8	12.6	7.91	3.79
Area (ha)	0.02	0.02	0.03	0.04	0.04	0.04	0.02	0.02
Ave rate (L/ha)	829	362	431	113	367	310	390	187
Change		-56.3%		-73.8%		-15.3%		-52.1%

leafhoppers, the use of pesticides might have also reduced the populations of their natural enemies. Frank and Sadof (2011) found that repeated use of a conventional, constant rate airblast sprayer decreased beneficial insects by 50%, while the number of maple spider mites (*Oligonychus aceris* Shimer) increased approximately twofold.

The decrease in leafhoppers with the intelligent spray treatment compared to the conventional treatment might have resulted from a reduction of non-target pesticide application, i.e., insecticide on the soil and non-target vegetation on the ground and air, reducing the adverse impacts to naturally occurring predators of potato leafhoppers. In these studies, intelligent sprayer technology reduced pesticide volume 66.4% across all sites and years. In other research of intelligent spray technology, non-target applications to surrounding vegetation were reduced 63.5% by using the intelligent sprayer (Fulcher et al. 2018). Natural enemies were not documented as part of this study; however, lady beetles, damsel bugs, green lacewings, and minute pirate bugs are known to prey upon potato leafhopper (Martinez and Pienkowski 1982). Our results indicate that applications of insecticides with intelligent spray technology can effectively control leafhoppers in maple crops while reducing environmental exposure to pesticides.

Control of aphids in birch. At Willoway Nurseries, there were fewer aphids on the birch trees sprayed with the intelligent spray mode than the conventional spray mode on two dates in 2017 and one date in 2018 (Table 8). In 2017, there were more aphids in plants treated with the intelligent spray mode on two dates at Herman Losely & Son (Fig. 10). However, in 2018 the number of aphids

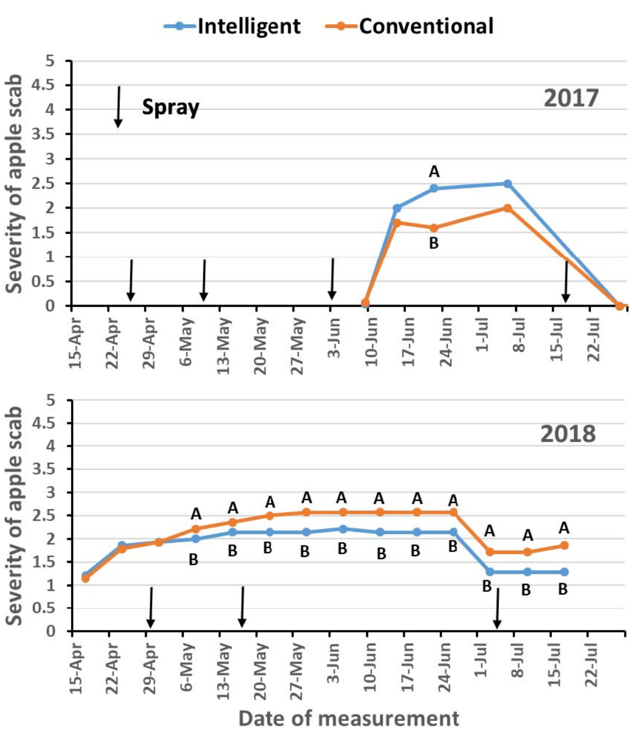

Fig. 8. Effect of intelligent and conventional spray on severity of scab in apple trees at Herman Losely & Son. Different letters in the same date are significantly different at the $P \leq 0.05$ level.

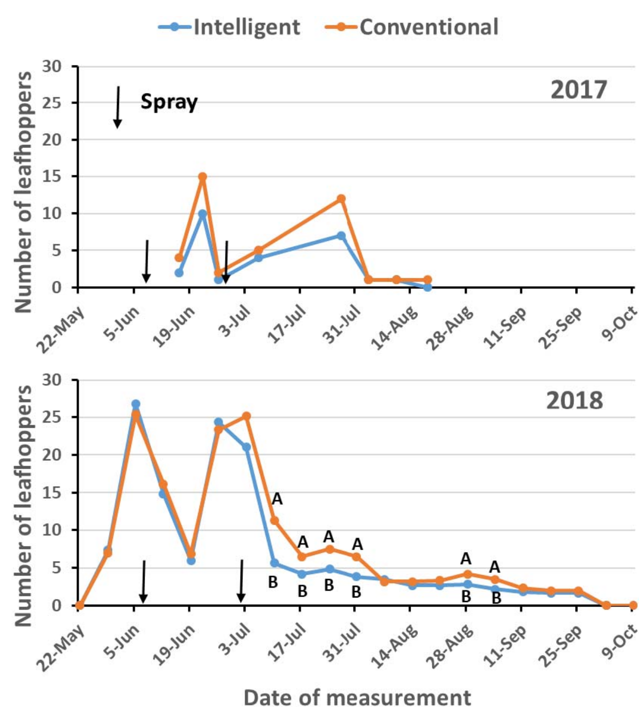

Fig. 9. The number of leafhoppers in sticky traps for maple trees treated by intelligent and conventional spray at Herman Losely & Son. Different letters in the same are significantly different at the $P \leq 0.05$ level.

Table 6. Effects of conventional (Con) and intelligent (Int) spray applications on pesticide use in 2017 and 2018 at Herman Losely & Son.

	Apple		Maple		Birch		Dogwood	
	Con	Int	Con	Int	Con	Int	Con	Int
2017								
Ave use (L)	23.5	10.4	37.6	11.4	42.3	24.8	23.5	12.5
Area (ha)	0.05	0.05	0.08	0.09	0.09	0.09	0.05	0.05
Ave rate (L/ha)	470	194	470	123	470	272	470	241
Change		-58.7%		-73.8%		-42.1%		-48.7%
2018								
Ave use (L)	23.5	8.24	37.6	22.2	42.3	19.2	23.5	18.2
Area (ha)	0.05	0.05	0.08	0.09	0.09	0.09	0.05	0.05
Ave rate (L/ha)	470	177	470	246	470	211	470	351
Change		-62.3%		-47.8%		-55.3%		-25.4%

in birch sprayed using intelligent spray technology was less on several days. For the same reason as the leafhoppers, the decrease of aphids for intelligent spray could have been due to an increase in the number of natural enemies of aphids such as small wasps, syrphid flies, and ladybird beetles (Hahn and Wold-Burkness 2019) resulting from a reduction of the adverse impact to the environment compared to conventional spray (Chen et al. 2013).

However, it is not clear why aphids were more prevalent for intelligent spray compared to conventional spray for the two measurement days in 2017. It is possible there was a higher insect density in the intelligent treated area given that the population difference was apparent in the beginning of the season. Approximately 20 days after the initial application, aphid levels were comparable and remained so for the duration of 2017 and 2018 while using a combined average of 40.7% less insecticide. Our results demonstrate that use of intelligent sprayers are as effective at controlling aphids in birch compared to the use of conventional sprayers.

Control of powdery mildew in London planetree and flowering dogwood. No powdery mildew was observed on London planetree at Willoway Nurseries. Dogwood powdery mildew severity at Herman Losely & Son is shown in Fig. 11. In 2017, powdery mildew was reduced among dogwoods treated using intelligent spray technology on one date compared to the conventional spray application. In 2018 powdery mildew in dogwood at Herman Losely & Son site appeared in early June and gradually increased until October. Compared to the conventional spray application, powdery mildew was reduced by intelligent spray technology after the first application. In two different seasons, dogwood powdery mildew control was not affected by use of intelligent technology (Fulcher et al. 2017, 2018), indicating that equivalent or greater powdery mildew control is possible using intelligent spray technology.

Flowering dogwood, the species used for this study, has been threatened by powdery mildew in the United States since 1994 (Li et al. 2009). Prior to the emergence of this fungus, flowering dogwood had few pest problems and required few pesticides during production. However, to control powdery mildew, a fungicide must be applied at 2-week intervals during the growing season. The costs of a

Table 7. Average leafhopper numbers in a sticky card in maple at Willoway Nurseries in 2017 and 2018.

2017			2018		
Date	Conventional spray	Intelligent spray	Date	Conventional spray	Intelligent spray
6/14/2017	4	3	6/14/2018	79 a[z]	36 b
6/23/2017	27	33	6/22/2018	307	276
6/29/2017	2	5	7/05/2018	115	82
7/07/2017	9	9	7/12/2018	12	5
7/13/2017	5	6	7/18/2018	20	18
7/26/2017	22	20	7/30/2018	111	85
8/02/2017	8	6	8/02/2018	23	22
8/09/2017	0	1	8/09/2018	16	10
9/01/2017	15	14	8/16/2018	7	7
			8/23/2018	8 a	2 b
			8/29/2018	8	4

[z]Means followed by a different letter for a given date within the same year are significantly different at the $P \leq 0.05$ level.

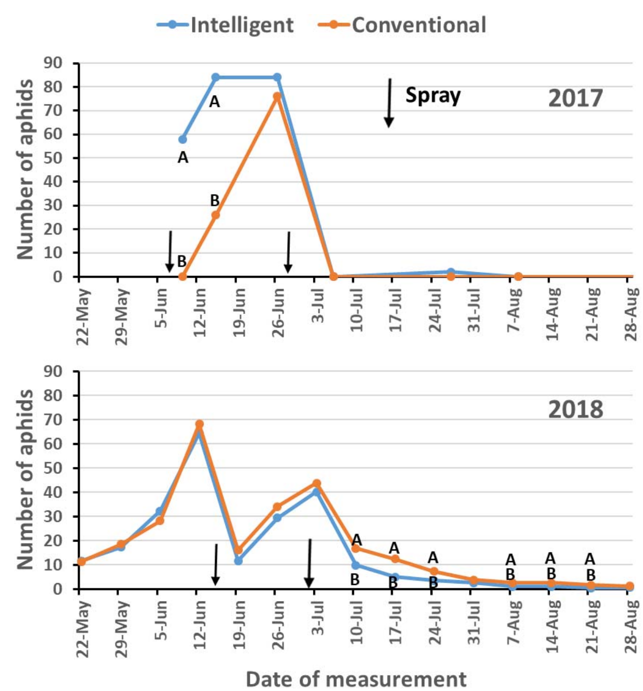

Fig. 10. The number of aphids in birch trees treated by intelligent and conventional spray at Herman Losely & Son. Different letters in the same date are significantly different at the $P \leq 0.05$.

Table 8. Average aphid numbers in birch at Willoway Nurseries in 2017 and 2018.

2017			2018		
Date	Conventional spray	Intelligent spray	Date	Conventional spray	Intelligent spray
6/08/2017	74 a[z]	24 b	7/06/2018	52	30
6/14/2017	88 a	38 b	7/12/2018	84 a	13 b
6/23/2017	0	0	7/23/2018	8	2
6/29/2017	2	0	7/30/2018	2	1
7/07/2017	0	2			
7/13/2017	0	0			

[z]Means followed by a different letter for a given date within the same year are significantly different at the $P \leq 0.05$ level.

fungicide management program greatly increased the overall production costs of the crop by around $2,000/ha/year ($810/acre/year), which many nurseries cannot afford (Li et al. 2009). Thus, intelligent spray technology can provide a highly efficient, low cost, and environmental-friendly pesticide spray technology for nurseries that produce flowering dogwood.

The London planetree cultivar 'Bloodgood' was used for this study. London planetree, a hybrid of American sycamore and Oriental planetree, is susceptible to powdery mildew (Gubler and Koike 2017). Powdery mildew on London planetree leaves was also found in Ohio during the growing season of 2018 (Fig. 6 B). However, no powdery mildew in London planetree occurred throughout the growing season at Willoway Nurseries, indicating that the fungicide deposition was sufficient to prevent it.

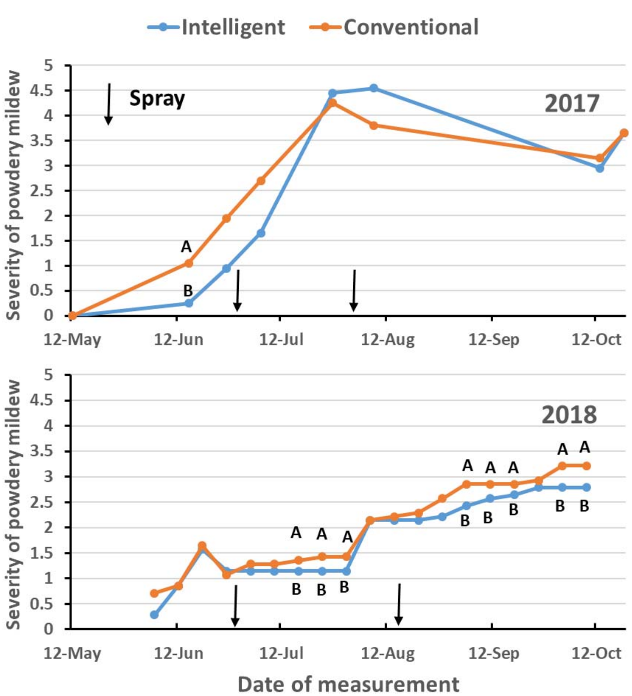

Fig. 11. Effect of intelligent and conventional spray on severity of powdery mildew in dogwood trees at Herman Losely & Son. Different letters in the same date are significantly different at the $P \leq 0.05$ level.

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