Research Article

Received: 10 September 2018 Revised: 17 December 2018 Accepted article published: 4 January 2019 Published online in Wiley Online Library: 10 February 2019

(wileyonlinelibrary.com) DOI 10.1002/ps.5310

Management of flatheaded appletree borer (Chrysobothris femorata Olivier) in woody ornamental nursery production with a winter cover crop

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Abstract

BACKGROUND: The flatheaded appletree borer (*Chrysobothris femorata* Olivier) (FHAB) is a native pest of fruit, shade and nut trees throughout the United States. Use of cover crops is an effective pest management tool for some key insect pests in vegetable and cereal production systems, but its impact in woody ornamental production systems has not been investigated. The goal of this study was to evaluate the effectiveness of a winter cover crop for management of FHAB in nursery production. Red maple trees (*Acer rubrum* L.) grown under four treatment regimes (cover crop, cover crop + insecticide, bare row and bare row + insecticide) were evaluated for damage by FHAB and impact on tree growth parameters.

RESULTS: The cover crop reduced FHAB damage, with results equivalent to standard imidacloprid treatments. The reduction in FHAB attacks in cover crop treatments may be due to microclimate changes at preferred oviposition sites, trunk camouflage or interference with access to oviposition sites. Tree growth was reduced in the cover crop treatments due to competition for resources.

CONCLUSION: Physical blockage of oviposition sites by cover crops and subsequent microclimate changes protected against FHAB damage. Therefore, cover crops can be an alternative to chemical insecticides.
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Supporting information may be found in the online version of this article.

Keywords: crimson clover; annual ryegrass; winter wheat; imidacloprid; barrier; red maple

1 INTRODUCTION

The flatheaded appletree borer, *Chrysobothris femorata* (Olivier) (Coleoptera: Buprestidae) (FHAB), is a serious pest throughout the United States and is reported as injurious to fruit, shade and nut trees.[1] The borer's distribution is ubiquitous, covering the entire continental United States and extending into Canada.[2,3] It has been reported as problematic for damage on ornamental trees in Oklahoma, Kentucky, Georgia, and Tennessee.[4,5] The wide host range of FHAB has made it difficult for orchard owners to exclude, despite continuous research efforts.[6] This borer can attack more than 30 species of trees.[7] The most common hosts are red maple (*Acer rubrum* L.), silver maple (*Acer saccharinum* L.), peach (*Prunus persica* L.), common apricot (*Prunus americana* Marsh), garden plum (*Prunus domestica* L.), apple (*Malus* spp.), different species of oak (*Quercus* spp.), American basswood (*Tilia americana* L.), and dogwood (*Cornus* spp.).[8] A single larva can completely girdle a tree within a single year.[5,9] Although trees attacked by FHAB do not always die, the trunk damage caused by larval tunneling ruins the economic quality of the nursery tree.[5,9] In general, newly transplanted maples have slightly higher rates of attack, but maples may continue to be attacked well after transplanting.[5] Individual trees may be repeatedly attacked over multiple years, which usually kills them.[1,10]

The most effective treatment for FHAB is a systemic drench application of imidacloprid, although dinotefuran drenches, and chlorpyrifos, bifenthrin and permethrin trunk sprays also are commonly used.[5] The seasonality of adult borer flights and egg deposition vary by region and environmental conditions in different years,[1,4,7,10] making it difficult to predict the optimal timing of trunk sprays. Generally, the FHAB life cycle is completed in 1 year with eggs deposited in late spring or early summer, but some larvae can take 2 years to complete their development, which also can cause differences in the timing of adult emergence.[1,7]

Previous research has demonstrated that nursery tree rows treated with pre-emergent herbicide have more FHAB attacks than trees with standing weeds at the base (Oliver JB *et al.*, unpublished). In this two-year trial, half the labeled high rate of imidacloprid resulted in 100% control in the non-herbicide-weedy treatment, but had a 15% loss in the herbicide treatment during that same

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period (Oliver JB *et al.*, unpublished). Based on the FHAB preference for depositing eggs near the base of the tree,[11] the authors hypothesized that the weeds provided protection from egg-laying by FHAB.

If a weedy barrier is sufficient to prevent or reduce FHAB attacks on trees, then a cover crop could be used in the same fashion. Commonly used winter cover crops in the southeastern United States include rye (*Secale cereale* L.), wheat (*Triticum aestivum* L.), clover (*Trifolium* spp.), vetch (*Vicia* spp.) and other crops.[12] A study of FHAB damage in red maple trees in weedy plots suggested that the height of borer damage averaged < 20 cm above the soil line, but ranged up to 100 cm.[5] Therefore, any cover crop used for FHAB management must reach a sufficient height to block beetles from accessing that portion of the tree at the time of female flight. Winter wheat serves as a winter crop or cover crop for weed[13] and erosion control.[14] The height of winter wheat varies with variety, but ranges from 78 to 102 cm.[15] The approximate date of maturity for winter wheat in Tennessee is the first week of June, but the plant will reach its full height by early May. Another common cover crop used in the southern United States is crimson clover (*Trifolium incarnatum* L.). Crimson clover is often used as a winter cover crop in vegetable or field crops[16] and may be planted in mixes with grains to provided supplemental nitrogen. Crimson clover grows to between 30 and 90 cm, and is an excellent green manure that can add 76.6–170.5 kg N ha^{-1} if it is allowed to reach the late bloom stage before being killed or turned under.[16,17] In Tennessee, growers generally apply 20–40 kg N to a production wheat field.[15] Therefore, clover supplies sufficient nitrogen to the field without the need to add more fertilizer to the wheat cover. Adult FHAB are predominantly active from mid-May to early July,[18] so the maximum height of wheat and clover in the late spring coincides with the likely oviposition period of FHAB. Therefore, it is predicted that that crimson clover and wheat would be at the ideal height to interfere with FHAB movement and oviposition around the tree trunk.

Although cover crop incorporation for insect pest management has been performed in vegetable and cereal production,[19,20] no research on the use of cover crops in red maple nursery production for insect pest management exists. Following the same principles as in vegetable and cereal farming, the objective of this study was to minimize FHAB damage in field-grown red maple. However, there are unique challenges in woody perennial production systems that are not present in seasonal vegetable and grain production. Normally, a cover crop is applied to a fallow field in between crop seasons. In a maple production system, tree liners must be transplanted while dormant in late fall or early spring. Fall or early spring planting may necessitate planting trees directly into a previously planted winter cover crop and overseeding the field following transplant. In subsequent years, the cover crop will need to be broadcast at the base of the trees, but can only be disked or drilled in the row middles to prevent damage to the tree roots. A winter cover crop is also likely to compete with the maple trees during early spring growth.

Based on our knowledge of FHAB behavior and the limitations of current conventional management practices, the goal of this study was to develop an alternative management method for FHAB in nursery production. The objectives of this study were two-fold: (i) to evaluate the effectiveness of a winter cover crop to protect maple trees from FHAB attacks, and (ii) to identify the impacts of a cover crop management strategy on tree growth.

2 MATERIALS AND METHODS

2.1 Experimental design

2.1.1 Field plots

Moore Nursery in Irving College, TN, USA (35.583889°N, 85.713056°W) (Warren Co.) was the field site for this study. Four treatments were assigned in a 2 × 2 factorial design. The treatments included: (i) cover crop, (ii) cover crop + insecticide, (iii) bare row (*via* standard nursery herbicides), and (iv) bare row + insecticide (Fig. S1). Treatment combinations were selected based on current recommended practices (bare row + insecticide), our practice of interest (cover crop in tree rows), a treatment with both cover crop and chemical controls (cover crop + insecticide) and a negative control to provide a baseline for FHAB activity (bare row). Each treatment block was replicated four times and consisted of an 11 × 11 m plot with 25 randomly assigned trees (i.e., 100 trees per treatment; 97.5 m × 24.4 m field site). Tree rows were spaced 2.1 m apart with 1.8 m within-row spacing between trees following current recommendations for a short duration planting.[21] A single tree space was skipped after the fifth tree in each row as a buffer zone between treatment plots.

2.1.2 Plant material

Red maple 'Franksred' liners were propagated as rooted cuttings in June 2014 and transplanted into #3 containers (C1200, 10.9 L, Hummert International, Earth City, MO, USA) in April 2015. Containers were top dressed with slow-release fertilizer (12N–6P–6K) (Harrell's Inc., Lakeland, FL, USA) and held under overhead irrigation until transplant the following fall. Four hundred dormant trees with an average trunk diameter of 1.13 ± 0.01 cm at 15 cm above the soil line and a height of 154 ± 0.80 cm were planted in ten rows on 13 November 2015 using a nursery tree planter (model TR-8, Rigsby Manufacturing Co., Walling, TN, USA) drawn by a John Deere 640 tractor (John Deere, Moline, IL, USA). Trees were top-dressed with fertilizer in March and June 2016 with a total of 22 g N $tree^{-1}$, and again in 2017 with a total of 31 g N $tree^{-1}$ of agricultural grade fertilizer (15N–15P–15K) (Harrell's Inc.), respectively, and pruned to develop or maintain a central leader and remove suckers. The amount of fertilizer was increased in the second year of the experiment to meet additional requirements for tree growth.

2.1.3 Cover crop application

Crimson clover and winter wheat (Adams-Briscoe Seed Co., Jackson, GA, USA) were sown before tree transplant on 15 October 2015 at half the recommended high rate (16.8 and 84.2 kg ha^{-1}, respectively)[22] using a Herd GT77 Spreader (Herd Seeder Co., Inc., Logansport, IN, USA). Half the high rate of cover crops was used because two cover crops were combined and no prior knowledge existed on how well they would work for FHAB control. A Kubota RTV1140 (Tractor and Equipment, Tennessee Valley, McMinnville, TN, USA) with the spreader attached was operated with a ground speed of 1 m s^{-1}. Seeds were lightly disked into the field following broadcast. Cover crops were allowed to senesce naturally through the summer months and row middles were disked into the soil on 11 August 2016 with a John Deere Model 770 tractor fitted with a 1.2 m (4 ft) wide model disc with scalloped edges (Rigsby Manufacturing Co.). Cover crops were allowed to senesce naturally in order to evaluate the maximum impact of the cover crop on tree growth.

For the second-year of the experiment, clover (16.8 kg ha^{-1}) and annual ryegrass (34 kg ha^{-1}) (*Lolium multiflorum* L.) were sown

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in September 2016 using a Scott's Edge Guard™ spreader (The Scotts Co. LLC, Marysville, OH, USA). Wheat was replaced with annual rye grass in the second year because, unlike wheat, ryegrass will germinate on contact with the ground and does not require disking in the tree rows.

2.1.4 Herbicide and insecticide application

Tree rows in plots with no cover crop were maintained bare with a program of pre- and post-emergent herbicides to control grass and broadleaf weeds. The pre-emergent (SureGuard®, flumioxazin 51%, Valent U.S.A. Corp., Walnut Creek, CA, USA) was applied at ∼6-month intervals or whenever vegetation began to break through the herbicide barrier. SureGuard was applied at a rate of 708.8 g product ha^{-1} in November 2015, March 2016, August 2016, and April 2017. The post-emergent herbicides Finale® (glufosinate-ammonium 11.33%, Bayer Environmental Science, Research Triangle Park, NC, USA) or Gly Star® Original (glyphosate 41%, Albaugh, LLC, Ankeny, IA, USA) with 80–20 (0.5%) surfactant (Ragan and Massey, Inc., Ponchatoula, LA, USA) were applied as spot treatments to control weeds that broke through the pre-emergent barrier.

Trees in the insecticide treatments were treated with a basal drench of Discus® N/G insecticide (imidacloprid 2.94% + 0.70% cyfluthrin; OHP, Inc., Bluffton, SC, USA) On 11 April 2016 at half the labeled rate (11 mL product 2.5 cm^{-1} of trunk diameter in 60 mL water) based on previous efficacy data (Oliver JB *et al*., unpublished).

2.2 Flatheaded appletree borer damage evaluation

All trees were evaluated for characteristic FHAB damage in fall and spring of year one (October 2016 and April 2017) and year two (October 2017 and April 2018). Height of attacks on tree trunks above the soil surface was recorded using the visible length of larval surface damage (i.e., bark that was cracked, split, missing, or sunken). If trees were attacked twice or a tree had two continuous boring tunnels, average lower height and average length were calculated. Direction of initial damage or any characteristics D-shaped holes were recorded and assigned to one of four quadrants: northeast, southeast, southwest and northwest. Although the adult borers oviposit on trees in late spring and early summer, the new larval damage is apparent only in the following fall or spring after the larva has grown and the damage increased. To make it useful for data analysis and interpretation purpose, we reported borer damage in the fall and following spring as damage from the same season.[5]

2.2.1 Cover crop height and biomass evaluation

For both cover crop treatments (i.e., with or without insecticide), measurement of cover crop height was performed biweekly from March to July 2016 and monthly in 2017 when biweekly recordings proved unnecessary. On 27 July 2016, 30 cm^2 cover crop samples were removed from each treatment plot at five randomly selected locations within the tree rows by cutting at ground level. The cover crops and weeds were separated. Separated materials were dried in an oven at 40 °C and dry weight was recorded. Final height of the cover crop was measured just before the cover crop was tilled into the soil on 27 July 2016 and 2017.

2.2.2 Trunk temperature evaluation

Trunk temperature on the southwest side of each tree at 20 cm height from the soil line was recorded biweekly from March to July 2016 and monthly in 2017 with an infrared crop temperature/external soil temperature meter (Spectrum Technologies, Inc., East Plainfield, IL, USA). Temperature measurement was changed to monthly in 2017 upon evaluation of biweekly measurements in the prior year. The height of temperature measurement was chosen as 20 cm because most attacks occur at or below 20 cm.[5,11]

2.3 Tree growth

Tree height and trunk diameter were recorded before transplant and repeated in September 2016 and 2017. Trunk diameter was measured using digital calipers (Mitutoyo Corp., Kanagawa, Japan) at 15 cm (6 in) above ground level. A permanent marker was used to create a mark on the tree trunk to facilitate subsequent measurements at the same location. Canopy size index (CSI) was recorded for all treatments in September 2016 and 2017 by the following formula: CSI = (canopy width at widest point + width perpendicular to widest point + canopy height)/3.[5]

2.4 Statistical analyses

Flatheaded appletree borer attack counts were analyzed with a generalized linear interactive model (PROC GENMOD) fitted to a negative binomial distribution and treatment LSmeans were separated by Tukey's Multiple Comparison Test (SAS 9.3, SAS Institute, Inc., Cary, NC, USA). The proportion of attacks by direction and height on the tree trunk were analyzed by chi-squared test of proportions (PROC FREQ). Biomass of dried cover crop and weeds samples, trunk temperature, tree height, diameter and canopy size index measurements of maple trees were analyzed by a generalized linear interactive model procedure (PROC GENMOD) fitted to a normal distribution with LSmeans separated by Tukey's multiple comparison test.

3 RESULTS

3.1 Flatheaded appletree borer damage

Of 26 FHAB damaged trees, two were found in the cover crop treatment (Fig. 1). Twenty-three damaged trees were in the bare row treatment (negative control) and one was in the bare row + insecticide treatment (current recommended practice). One tree from the bare row treatment was attacked in both years. The cover crop treatments reduced FHAB attacks whether or not insecticide was applied (cover: χ^2 (1) = 26.60, $P < 0.001$). There was a significant interaction of cover crop and insecticide treatments on FHAB attacks, with a stronger effect of insecticide observed in the bare ground treatments (insecticide: χ^2 (1) = 26.60, $P < 0.001$; cover × insecticide: χ^2 (1) = 22.17, $P < 0.001$). There was no difference in FHAB attacks detected between cover crop with and without insecticide (Fig. 1).

The average lowest and highest average height of FHAB damage was 7.84 ± 2.41 and 19.62 ± 2.61 cm above the soil line, respectively. Most of the observed damage (88.46%) was concentrated below 20 cm on the trunk (χ^2 (3) = 14.89, $P = 0.0019$; Fig. S2). Attacks were initiated from ground level and larvae tunneled upward. No larval damage was observed above 39 cm on any of the trees. On average, damage faced southwest (189.09° ± 16.02°) with 77.27% of all damage recorded on the southern-facing direction of the tree trunk (χ^2 (3) = 33.04, $P < 0.0001$; Fig. S3).

3.1.1 Cover crop height and biomass

The height of the cover crop in the first week of April 2016 was 24.8 ± 2.5 and 27.25 ± 2.3 cm, and the first week of April 2017 was

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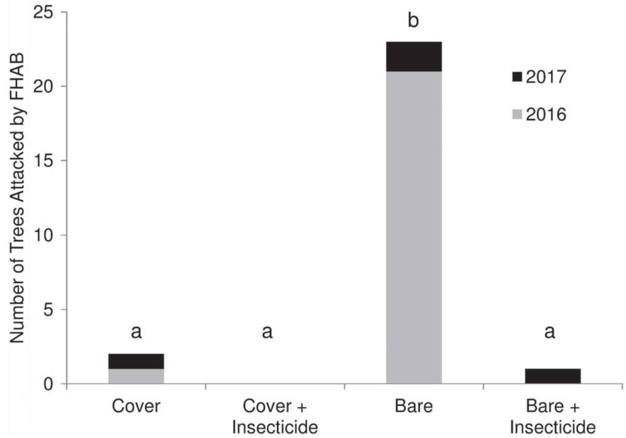

Figure 1. Total number of trees attacked by flatheaded appletree borer (FHAB). Values with different letters are statistically different. Cover = cover crops in tree rows were crimson clover and winter wheat (2016), and crimson clover and annual rye grass (2017). Bare = rows were maintained weed-free with pre- and post-emergent herbicides. Insecticide = trees were drenched with 0.5× labeled rate of Discus N/G (imidacloprid + cyfluthrin) in April 2016.

29.3 ± 2.0 and 33.2 ± 2.4 cm in the cover + insecticide and cover crop treatments, respectively. There was no difference detected in initial height of cover crops in either of the treatments (2016; χ^2 (1) = 0.54, P = 0.463, 2017; χ^2 (1) = 0.90, P = 0.344). However, the average initial height of cover crop was higher in 2017 (height: χ^2 (1) = 4.05, P = 0.044). The heights of cover crop in first week of May 2016 were 65.22 ± 3.6 and 70.92 ± 3.57 cm, and in 2017 were 72.67 ± 2.24 and 71.69 ± 1.94 cm for the cover + insecticide and cover crop only treatments, respectively. The final height of the cover crop the last week of June 2016 was 92.6 ± 6.3 and 89.3 ± 2.4 cm, and in last week of June 2017 was 70.3 ± 4.8 and 72.0 ± 5.0 for the cover + insecticide and cover crop only treatments, respectively. No differences were observed between either of the treatments in both years (2016: χ^2 (1) = 0.12, P = 0.734, 2017; χ^2 (1) = 0.01, P = 0.94). However, the average final height of cover crops was lower in 2017 than in 2016 (height: χ^2 (1) = 59.72, P < 0.001).

In 2016, weeds broke through the cover-cropped tree rows as the cover senesced and there was no difference in dry weight of cover crop and weeds in the harvested row samples (weeds: 26.7 ± 8.19 g, cover crop: 32.65 ± 1.68 g; dry weight: χ^2 (1) = 1.05, P = 0.306). Similarly, there was no difference in cover crop dry weights between cover + insecticide (34.77 ± 1.8 g) and cover only (30.53 ± 1.6 g) treatments (dry weight: χ^2 (1) = 3.16, P = 0.076) in 2017. In 2017, however, fewer weeds were observed in the cover-cropped tree rows at the end of the evaluation period, and the dry weight of cover crop outweighed the weeds (weeds: 43.88 ± 14.97 g, cover crop: 188.0 ± 14.55 g; dry weight: χ^2 (1) = 85.30, P < 0.001). Similarly, there was no difference in cover crop weights between cover + insecticide (181.62 ± 15.22 g) and cover only (186.36 ± 13.87 g) treatments (dry weight: χ^2 (1) = 0.05, P = 0.818).

3.1.2 *Trunk temperature*

Trunk temperatures at 20 cm were lower in the cover crop treatments compared with bare row treatments throughout the 2016 effective cover crop standing period (cover: χ^2 (1) = 88.80, P < 0.001) (Fig. 2A). There was no effect of insecticide application on trunk temperature (insecticide: χ^2 (1) = 0.39, P = 0.534) and no interaction of row treatment and insecticide (cover × insecticide: χ^2 (1) = 0.00, P = 0.951). Overall, the effect of temperature reduction was similar in 2017 during the cover crop period (cover: χ^2 (1) = 25.48, P < 0.001, insecticide: χ^2 (1) = 4.01, P = 0.045, cover × insecticide: χ^2 (1) = 0.89, P = 0.345) (Fig. 2B). However, there was upward trend of temperature during last week of June in cover crop applied treatments as the cover crop senesced more quickly in 2017 (Fig. 2B). Trunk temperatures were lowest at the first sampling date of each year and gradually increased throughout the late spring and early summer to a peak in June (Fig. 2B).

3.2 Tree growth

3.2.1 *Height*

At transplant, average heights of experimental trees were similar across all treatments (Table 1). In October 2016, at 1 year post transplant (2016), treatments without cover crops grew more than cover crop treatments (cover: χ^2 (1) = 493.05, P < 0.001). There was a significant interaction between cover crop treatments and insecticide treatments (insecticide: χ^2 (1) = 47.49, P < 0.001; cover × insecticide: χ^2 (1) = 32.52, P < 0.001), where insecticide application in treatments with bare rows was found to enhance plant height. In September 2017, treatments with bare rows again had a better height growth than cover-cropped trees (cover: χ^2 (1) = 5.32, P < 0.001). However, no effect of insecticide was observed in year two (insecticide: χ^2 (1) = 0.43, P = 0.511), nor was there a significant interaction of cover and insecticide treatments (cover × insecticide: χ^2 (1) = 0.29, P = 0.592).

3.2.2 *Trunk diameter*

There was no difference in average diameter for all newly transplanted trees in October 2015 (Table 1). However, by October 2016, trunk diameter growth was greater in trees in bare rows compared with cover-cropped trees (cover: χ^2 (1) = 278.75, P < 0.001). Insecticide application did not affect diameter growth in cover crop treatments, but did increase diameter in the bare row treatment (insecticide: χ^2 (1) = 2.28, P = 0.131, cover × insecticide: χ^2 (1) = 10.64, P = 0.001). In September 2017, similar results were observed where trees in bare rows had greater diameter growth (cover: χ^2 (1) = 70.17, P < 0.001; Table 1), as did trees with insecticide applied (insecticide: χ^2 (1) = 4.40, P = 0.036). However, no interaction between cover treatments and insecticide (cover × insecticide: $\chi^2{}_{(1)}$ = 0.00, P = 0.95) was observed in year two.

3.2.3 *Canopy size index*

In fall 2016, tree canopy size was smaller in trees grown with cover crops compared with trees grown in bare rows (cover: χ^2 (1) = 536.62, P < 0.001; Table 2). The application of insecticide also increased canopy size (insecticide: χ^2 (1) = 47.57, P < 0.001). There was also an interaction of cover and insecticide treatments (cover × interaction: χ^2 (1) = 24.64, P < 0.001) with the insecticide effect stronger in the bare row treatments. In 2017, results were similar to 2016 for cover treatments (cover: χ^2 (1) = 241.27, P < 0.001) and insecticide application (insecticide: χ^2 (1) = 9.46, P = 0.002), but there was no interaction (cover × interaction: χ^2 (1) = 1.31, P = 0.252).

4 DISCUSSION

Flatheaded appletree borer has a preference for ovipositing on the lower trunk of host trees.[5,11] The FHAB height preference

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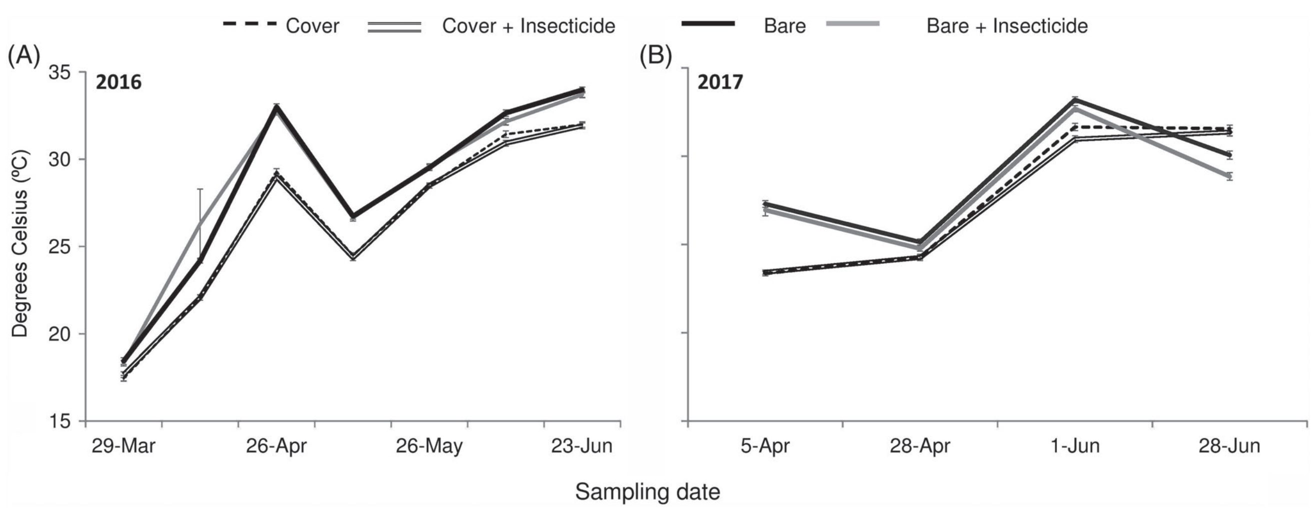

Figure 2. (A) Biweekly trunk temperature (°C ± SEM) at 20 cm above the soil surface in 2016. (B) Monthly trunk temperature (°C ± SEM) at 20 cm above the soil surface in 2017. Cover = cover crops in tree rows were crimson clover and winter wheat (2016), and crimson clover and annual rye grass (2017). Bare = rows were maintained weed-free with pre- and post-emergent herbicides. Insecticide = trees were drenched with 0.5× labeled rate of Discus N/G (imidacloprid + cyfluthrin) in April 2016.

Table 1. Increase in height and trunk diameter of 'Franksred' red maple trees grown under four management regimes 1 and 2 years post transplant

	Height (cm)			Diameter (cm)		
Treatments	Initial height 2015[a]	Growth 2016	Growth 2017	Initial diameter 2015	Growth 2016	Growth 2017
Cover	153.72 ± 3.06*a*	8.26 ± 1.18*c*	56.09 ± 2.94*b*	1.13 ± 0.02*a*	0.41 ± 0.10*c*	0.73 ± 0.11*b*
Cover + Insecticide	157.23 ± 3.18*a*	10.59 ± 1.45*c*	56.47 ± 2.46*b*	1.14 ± 0.02*a*	0.31 ± 0.01*c*	0.86 ± 0.03*b*
Bare	153.03 ± 2.71*a*	40.60 ± 1.84*b*	79.91 ± 4.37*a*	1.13 ± 0.02*a*	1.17 ± 0.03*b*	1.25 ± 0.04*a*
Bare + Insecticide	155.74 ± 2.18*a*	65.28 ± 2.92*a*	83.68 ± 2.45*a*	1.12 ± 0.01*a*	1.44 ± 0.03*a*	1.38 ± 0.03*a*

[a]Values with different letters are statistically different. Cover = cover crops in tree rows were crimson clover and winter wheat (2016), and crimson clover and annual rye grass (2017). Bare = rows were maintained weed- free with pre- and post-emergent herbicides. Insecticide = trees were drenched with 0.5× labeled rate of Discus N/G (imidacloprid + cyfluthrin) in April 2016.

Table 2. Mean canopy size index of 'Franksred' red maple trees 1 and 2 years post transplant

	Canopy size index (cm^3)	
Treatments[a]	2016	2017
Cover	52.30 ± 1.03*c*	76.9 ± 1.59*c*
Cover + Insecticide	54.35 ± 1.21*c*	79.8 ± 1.66*c*
Bare	90.42 ± 1.33*b*	108.4 ± 1.85*b*
Bare + Insecticide	113.29 ± 1.80*a*	117.7 ± 1.02*a*

[a] Values with different letters are statistically. Cover = cover crops in tree rows were crimson clover and winter wheat (2016), and crimson clover and annual rye grass (2017). Bare = rows were maintained weed-free with pre- and post-emergent herbicides. Insecticide = trees were drenched with 0.5× labeled rate of Discus N/G (imidacloprid + cyfluthrin) in April 2016.

observation led to the proposal that incorporating a plant-related barrier to FHAB access around the base of tree trunks could protect nursery trees from attack. The results of this two-year study confirmed that attacks on red maple trees can be prevented by growing a winter cover crop at the base of trees. Only 2% tree loss was observed in the cover crop plots over the course of the study, whereas 1% tree loss was observed in plots with the currently recommended best practice, where trees were grown in bare rows and treated with basal drenches of imidacloprid. Although these two management methods provided significant levels of FHAB control, 23% of unprotected trees were lost over the two-year trial period. The 23% level of loss is typical for susceptible trees in nursery production areas where FHAB is present.[5]

There are at least three possible mechanisms by which the cover crops protected the trees from FHAB attack. The beetles are reported to be heliophilic, targeting their oviposition mostly on the sunny side of the tree (i.e., primarily the south and southwestern sides in our locality)[5,11] Sunny locations might be preferred for oviposition by wood-boring females because the added heat will accelerate development of the larvae.[11,23] The growth of the cover crop around the base of the tree decreased the entry of sunlight throughout the female oviposition period. The lower light penetration resulted in measurably lower trunk temperatures. Trunk temperatures were routinely 2 °C higher in the bare row treatments, and as much as 4 °C higher on extremely hot days in 2016. Although the temperature differences were less dramatic in the 2017 cover crop mix, bare row treatments remained consistently higher in all but the final sample date.

In addition to lower light penetration, the cover crop could have provided a simple physical barrier to FHAB that also may have deterred attacks. The height of both cover crops was > 30 cm starting in May and gradually increased to 70+ cm at the end of June.

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The May to June period coincided with the active FHAB flight period of May to July[18] and was sufficient to block FHAB oviposition based on our results. A study conducted simultaneously with this one attempted to use tree wraps to block FHAB attack.[24] They evaluated several types of tree guards commonly used in forestry to protect the trunks of newly transplanted trees. None of the products protected trees from FHAB over the three-year study. Females were able to enter the small amount of airspace left between the rigid tree wraps and the trunk. In the biodegradable paper treatment, females were able to reach the tree by crawling under the wraps. Trunk wraps likely increased the temperature and humidity of the tree trunks, as evidenced by the higher incidence of *Nectria* canker in the rigid tree guard treatments.[24] The ability of FHAB females to overcome physical barriers placed on host trees suggests that some other characteristic of the cover crop protected trees from FHAB females. In addition to physically blocking the tree trunk, the presence of a cover crop also may confuse specialist pests like FHAB, reducing colonization success.[25] Alternatively, the cover crop could have altered the predation risk of female FHAB.[25–27]

Basal drenches of imidacloprid provided 99–100% control of FHAB in this study. Current recommendations for FHAB control include a basal drench of a neonicotinoid (imidacloprid or dinotefuran). Imidacloprid, in particular, is an effective control of FHAB damage and the insecticide can persist in the plants for two or more years, allowing growers to treat once for a multiyear production cycle.[5] In many cropping systems, the use of imidacloprid is positively correlated with plant growth.[28–32] Similarly, in our study during the first year we found that height, diameter and canopy size increased due to the application of insecticides, especially in the bare rows. The effect of imidacloprid on plant growth parameters were reported as a phytotonic effect.[33,34] However, this system of phytotonic effects was mostly investigated field crops[32] like okra and cotton. Similarly, the effect of imidacloprid on red maple plant growth parameters was inconsistent over the two years of replication in our research, and thus imidacloprid cannot be recommended as a plant growth-enhancing agent in red maple production system. Imidacloprid and other neonicotinoids have been associated with potential negative effects on pollinators, especially bees.[35–37] In addition to non-target impacts, the use of a sole active ingredient for FHAB control on a regional level has the potential to result in resistance development in FHAB populations. The cover crop management method provides flexibility to growers and an alternative to neonicotinoids, particularly on flowering tree species.

Based on our results, cover crops that stand at least 30 cm before the female flight period are sufficient to protect trees against FHAB without the need for chemical treatments. In addition to protection from FHAB, cover cropping can provide growers with other key benefits. Cover crops can be used to manage soil and water erosion,[38–40] increase soil organic matter,[41,42] as well as create alternative hosts and habitat for beneficial insects.[43,44] Cover crops may reduce the incidence of soilborne pathogens,[45] provide weed suppression[46–48] and reduce the attack of non-targeted arthropod pests of red maple.[49] Summer weeds, including ragweed, are difficult to manage in local nursery plantings. Weeds are all known for competing with main crops for moisture and nutrients, reducing primary crop growth in a nursery production system.[50] Ragweed suppression was noted in the second year of this study, suggesting that repeated use of cover crops can aid in the management of even recalcitrant weeds. Although cover crop species were not selected specifically for this study with weed suppression in mind, other winter cover crops, such as cereal rye (*Secale cereale* L.), could provide improved summer weed suppression.[51] In addition to weed suppression, greenhouse bioassays conducted using soils from this field study suggest that cover-cropped soils can suppress pathogens of concern to maple production including *Rhizoctonia solani* (J.G. Kühn) and *Phytophthora nicotianae* (Breda de Haan).[52] Trees in cover crop plots also had cooler trunks, so sunscald and temperature-related trunk stress may be reduced. In addition to the broader positive impacts of cover cropping, this management practice also may benefit nursery producers by reducing worker pesticide exposure and eliminating the considerable labor time and cost it takes to treat trees with insecticide drenches.

The major negative impact of the cover crop management method was the reduction in tree growth. Tree growth reduction was not an unexpected outcome, as cover crops can impede the growth of trees due to competition for soil resources.[53] The effect of competition has been shown in several woody plant systems. The study of ground covers on a Pejibaye peach palm (*Bactris gasipaes* Kunth) orchard system showed that ground covers impeded growth, lowered yield and delayed the harvest during the first one and half years.[54] The same principle of cover cropping also was investigated for vine growth in first-year vineyards.[55] In that study, cover crops reduced the vine dry mass weight by up to three- quarters compared with cover-free systems, but were able to suppress weed biomass by up to 95%. The similar dry biomass between cover crop and weeds in the first year of replication suggests that weeds also contribute to the reduction in tree growth. Similarly, when cover crop biomass outweighed weed biomass in the second year of replication, there was less difference in plant growth parameters between cover crop and bare treatments. Therefore, it is also important to keep weeds under control in a cover-cropped field.

Although the difference in maple tree growth between cover-cropped and bare row treatments was substantial in the first year post transplant, the difference decreased the second year (Tables 1 and 2). For example, trees in the cover crop treatment added only 12% of the height gained by the trees in the bare row + insecticide treatment in year one. In the second year, however, cover-cropped trees added 67% of the height gained by the bare row + insecticide-treated trees. Although the cumulative differences in growth are substantial, it is clear that the competitive advantage of the bare row treatment decreased once the trees were established. Although FHAB can continue to attack trees during the entire production cycle of a nursery tree,[5] many authors report this pest to be the most significant to tree crops during the initial transplant years.[1,10]

To the best of our knowledge, this is the first study to explore the effect of cover cropping on borer management in a nursery production system. Flatheaded appletree borer, a major insect pest of deciduous nursery trees in the United States, was efficiently controlled using a winter cover crop. This research provides an alternative to imidacloprid treatment for managing FHAB and potentially other species with similar life habits such as the Pacific flatheaded borer, *Chrysobothris mali* Horn.[7] An additional alternative to imidacloprid for FHAB management could be very important in the event of regulatory loss of imidacloprid registrations due to pollinator concerns or the development of FHAB imidacloprid resistance. Future avenues of research must address cover crop species selection and early senescence of the cover crop with herbicides to minimize the impact of the cover crop on tree growth. In addition, a significant factor to explore is the use of irrigation to mitigate tree growth losses from competing vegetation, by eliminating

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moisture competition. Traditionally, field-grown nursery crops in the southeastern United States are not grown under irrigation, as was the case in this study. However, regular irrigation of newly transplanted trees is known to have a positive effect on growth and could greatly reduce the impact of cover crops observed in this study. The knowledge gained from this study will support future evaluations of cover crops as a pest management tool in woody ornamental production.

ACKNOWLEDGEMENTS

We thank Mr Benji Moore at Moore Nursery for collaborating with us on this project. We thank Nadeer Youssef, Manoj Pandey, Matt Brown, Josh Basham, Debbie Eskandarnia, Megan Patton and Garrett Roper for assistance with data collection. This project was funded in part by Southern SARE (OS14-084) and NIFA Evans-Allen (1007887).

SUPPORTING INFORMATION

Supporting information may be found in the online version of this article.

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