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Efficacy of Flupyradifurone, Pyriproxyfen and Horticultural Oil, and Dinotefuran Against Gloomy Scale (*Melanaspis tenebricosa* Comstock)

By Kevin D. Chase, Elden LeBrun, and Chad M. Rigsby

Abstract. Gloomy scale (GS)(*Melanaspis tenebricosa*) is a major pest of red maple (*Acer rubrum*) across much of the eastern USA. Current pesticide recommendations for GS management are efficacious when applications are made at the appropriate time. However, appropriate timing may not always be possible. For instance, the tree owner may not contact pest management professionals in time to make timely applications. We established a field trial to determine the efficacy of the pesticides pyriproxyfen plus horticultural oil and dinotefuran, as well as a relatively new pesticide available in the ornamental woody plant market, flupyradifurone, against GS. There were three primary goals of this study: (1) to quantitatively compare the effectiveness of pyriproxyfen plus horticultural oil and dinotefuran; (2) to compare flupyradifurone with these two generally recommended treatments; and (3) to assess whether flupyradifurone is effective when applications are made later in the summer. We found that pyriproxyfen plus horticultural oil, dinotefuran, and flupyradifurone applications made during the active crawler period were equally efficacious, statistically, and that flupyradifurone treatments applied later in the summer were not statistically differentiable from untreated controls. While these pesticide applications are effective at suppressing GS populations, plant health care tactics aimed at preventing outbreaks should be prioritized and incorporated into the complete pest management strategy.

Keywords. Armored Scale; Pesticide Trial; Urban Trees.

INTRODUCTION

Red maple (*Acer rubrum* L.) is among the most commonly planted trees in the urban landscape throughout the eastern and central United States (Raupp et al. 2006). The popularity of this species stems from its ability to tolerate a variety of environmental conditions, its fast growth rate, and its autumn coloration (Frank et al. 2013). There is a wide range of *A. rubrum* cultivars available from the nursery industry. However, these trees can be afflicted with issues such as micronutrient deficiencies in alkaline soils, the formation of girdling roots, sun scalding, and structural defects due to codominant stems (Gilman and Watson 1993).

The dominant insect pest afflicting *A. rubrum*, specifically in southeastern and mid-Atlantic states, is gloomy scale (GS), *Melanaspis tenebricosa* Comstock (Hemiptera: Diaspididae). GS is an armored scale, which are among the most difficult insects to manage in urban landscapes (Braman et al. 2015). Tests (i.e., the insect's armored shells) from previous years remain on bark for several years. They are unsightly and may be confused with honeydew and resulting sooty mold, which is not produced by GS. Dale and Frank (2014) found that *A. rubrum* in urban settings are especially prone to GS infestations and poor health. Severe GS infestations can kill trees, usually in conjunction with poor cultural practices and inclement weather events.

Management recommendations for GS involve cultural, biological, mechanical, and chemical controls to varying degrees, depending on site conditions and severity of the infestation (Frank and Dale 2019). For example, choosing a planting site where summer heat will not be amplified by buildings or parking lots and appropriate watering are good cultural practices. Pruning out infested branches may be helpful when light infestations occur. Practicing conservation biological control, where habitat is provided for natural enemies, while eliminating or minimizing the exposure of beneficial organisms to insecticides will help suppress GS populations (Frank et al. 2013; Frank and Dale 2019).

Various chemical products can be used to aid in gloomy scale management. Application of horticultural oil during crawler activity in the spring and/or during the dormant season are common recommendations for armored scales. Insect growth regulators (e.g., pyriproxyfen) can also provide effective management of gloomy scale and other armored scales (Rebek and Sadof 2003; Raupp et al. 2008; Frank and Dale 2019). However, these treatments must be made when crawlers are present, and full coverage of the plant must be achieved.

Systemic products allow for additional “forgiveness” relative to topical products because they can be applied prior to scale emergence, and the residual may last through the entirety of the crawler emergence and settling phase. One of the most commonly used groups of systemic insecticides in the green industry is the neonicotinoids, which includes acetamiprid and dinotefuran. These products can be applied as a foliar, basal bark, and/or soil drench application. These products are effective for armored scale management (e.g., Cowles 2010) and can be excellent options in areas that do not have restrictions or bans on their use (Buzzetti et al. 2015; Frank and Dale 2019). Caution must be taken when applying neonicotinoids, because their presence has been detected in nectar and leaves in the following year post-application (Mach et al. 2018).

A relatively recent pest management product introduced to the green industry is flupyradifurone. Flupyradifurone is a group 4D insecticide with a relatively favorable toxicological and ecotoxicological profile and different structural properties than other insecticides of this group (Jeschke et al. 2015; Nauen et al. 2015). Unlike group 4A products that can be soil-applied, bark-applied, or injected, flupyradifurone does not appear to translocate through xylem of large trees, but will move upward into the foliage in smaller herbaceous plants like soybean (Stamm et al. 2016). Flupyradifurone, however, will translocate in smaller, container-grown woody plants or when foliar-applied to lateral branches via apoplastic xylem transport (Nauen et al. 2015). Foliar applications of flupyradifurone have been shown to be very effective in the management of several piercing-sucking pest systems such as aphids (Nauen et al. 2015; Lahiri et al. 2019), mealybugs (Ganjisaffar et al. 2019), psyllids (Chen et al. 2017), scales (Grafton-Cardwell and Scott 2015), and whiteflies (Nauen et al. 2015; Roditakis et al. 2017).

The purpose of this study was (1) to quantitatively compare the effectiveness of two generally recommended chemical treatments for gloomy scale, the combination of pyriproxyfen plus horticultural oil and dinotefuran alone, and (2) compare flupyradifurone with these two generally recommended treatments. Additionally, we sought to (3) assess the flexibility of flupyradifurone with regards to the post-settling phase of GS crawlers. As stated previously, in order to treat effectively for GS with products, applications of pyriproxyfen plus horticultural oil should be made once crawler activity is detected. The crawler activity window can be 6 to 8 weeks long, and crawlers will gradually emerge over that time. Issues can arise when property owners contact pest management specialists after this window. In these instances, practitioners will likely have to wait until the following growing season to treat for GS. Therefore, we wanted to explore the potential for the use of flupyradifurone at other times during the growing season to evaluate the efficacy of this product outside of the traditional treatment window. We present the results of a study comparing different products and timing for the management of GS.

MATERIALS AND METHODS

Research Site

We selected 54 semi-mature, GS-infested red maple trees located along the street right-of-way at the Walkers Ridge Community in Rock Hill, South Carolina, USA, with permission from the Walkers Ridge Home Owners Association. All trees were planted over a 2-year period between 2008 and 2010; therefore, the trees in this study were between 9 and 11 years old. Backe and Frank (2019) found that trees did not become infested with GS until at least 7 seasons after trees are planted. Additionally, they reported a delay between the first observation of GS and a noticeable decline in tree health. The *A. rubrum* at this site were visibly infested with GS but not yet displaying a decline in tree health.

Trees that were maintained by adjacent homeowners, trees that we did not have permission to include in this study, trees that were in poor condition upon visual inspection, and trees that did not readily appear to have high densities of GS were not included.

Table 1. Insecticide products used in efficacy trial against gloomy scale in Rock Hill, South Carolina, USA in 2019.

Product	Manufacturer	Active ingredient (AI)	% AI	Rate used (per 378.54 L [100 gal])	Application method	Date(s) of treatment
Distance*	Valent Corporation, Walnut Creek, CA, USA	Pyriproxyfen	11.23	236.59 mL (8 oz)	Foliar	23 May
Horticultural oil*	Lesco Inc., Cleveland, OH, USA	Refined petroleum distillate	98.8	1892.71 mL (0.5 gal)	Foliar	23 May
Transtect	Rainbow Treecare Scientific Advancements, Minnetonka, MN, USA	Dinotefuran	70	10,646.5 mL (360 oz)	Basal bark spray	29 May
Altus	Bayer, Leverkusen, Germany	Flupyradifurone	17.09	310.52 mL (10.5 oz)	Foliar	23 May (T_1), 2 July (T_2), 30 August (T_3)

*These products were mixed together for this trial.

Products, Rates, and Experimental Design

We selected products (Table 1) based on their historic use (pyriproxyfen, dinotefuran) and potential to be included into a GS management program (flupyradifurone). Each GS tree was assigned randomly to 1 of 6 treatments using a Microsoft Excel spreadsheet: untreated controls, dinotefuran applied during crawler activity (29 May), pyriproxyfen plus horticultural oil applied in the spring during crawler activity (23 May), flupyradifurone applied in the spring during crawler activity (T_1; 23 May), flupyradifurone applied in mid-summer (T_2; 2 July), and flupyradifurone applied in late summer (T_3; 30 August). All treatments were conducted in the year 2019. Tree diameter at breast height (DBH) ranged from 7.3 cm (2.9 in) to 19.1 cm (7.5 in).

All products were applied according to the label (Table 1). We applied 59.14 mL/2.54 cm (2 oz/1 in) DBH of dinotefuran as a basal bark spray with a backpack sprayer (15.14L Chapin Commercial Backpack Sprayer [Model 61900], Batavia, NY) at 96.53 kPa (14 psi) CFV and an 8006 TeeJet® fan nozzle (Springfield, IL). A surfactant (Scrimmage, Exacto Inc., Sharon, WI) was added to dinotefuran at a rate of 88.7 mL/3.78 L (3 oz/1 gal) water. We applied the dinotefuran and surfactant mix until the bark was wet from a height of approximately 1.37 m (4.5 ft) to the ground.

In this study, we combined pyriproxyfen with horticultural oil (see Table 1). Combining pyriproxyfen with horticultural oil is a standard practice, and recent research (Quesada et al. 2018) has shown that oil is superior to soaps at suppressing armored scales. All foliar flupyradifurone and pyriproxyfen plus horticultural oil applications (Table 1) were conducted with a Green Garde JD9-C spray gun (H.D. Hudson Manufacturing Co., Lowell, MI) from a rig specifically designed for plant health care operations at a pressure between approximately 1034 to 1378 kPa (150 to 200 psi). Lesco Spreader-Sticker (Lesco Inc., Cleveland, OH) was added to all flupyradifurone applications at a rate of 1.77 mL/3.78 L (0.06 oz/1 gal) water. Control trees had no treatment applied. All treatments had 9 replicates.

Evaluation and Statistical Comparisons

Six branches (technical replicates) were harvested from each tree (biological replicate) on 28 October 2019 using pole clippers and hand pruners, trimmed to 15 cm in length, placed in plastic bags, and immediately transported to the Bartlett Tree Research Laboratories where they were stored at 4 °C until scale densities could be counted. The branches selected for density counts were of similar diameter and among the most heavily infested with GS on the trees. Once at the laboratory, GS-infested branches were cut into lengths of 152 mm and then individually inspected using a standard dissecting scope. We counted live GS and obtained a ratio of the number of live GS per mm length of branch. High levels of GS survival (≥ 75%) were observed on trees in some of our treatments (e.g., untreated control trees). In these instances with high survival, branches were trimmed from 152 mm to a minimum of 30 mm, and survival was counted on this trimmed section of stem to obtain the ratio. This was done in order to decrease the time it took to perform counts on these branches. We determined if the adult scale was alive or dead by flipping over the test with a sharp probe and inserting the probe into the soft-bodied insect. If the insect exuded fluids, we counted the GS as "alive." The average GS density per mm of branch across the 6 branches were calculated, averaged, and used as the GS density for that individual tree.

To elucidate the effect of treatments on GS densities, a one-way analysis of variance (ANOVA) was used with average live GS density per mm of branch per tree as the response variable and treatment as the predictor variable. A post-hoc Dunnett's test was used to compare pesticide treatment means against the control treatment mean to determine which pesticides provided a meaningful level of GS suppression. GS density mean, standard deviation, standard error, 95% confidence interval, and median were calculated for all treatments. All statistics were performed in JMP (JMP Version 14. SAS Institute Inc., Cary, NC, USA, 1989–2007).

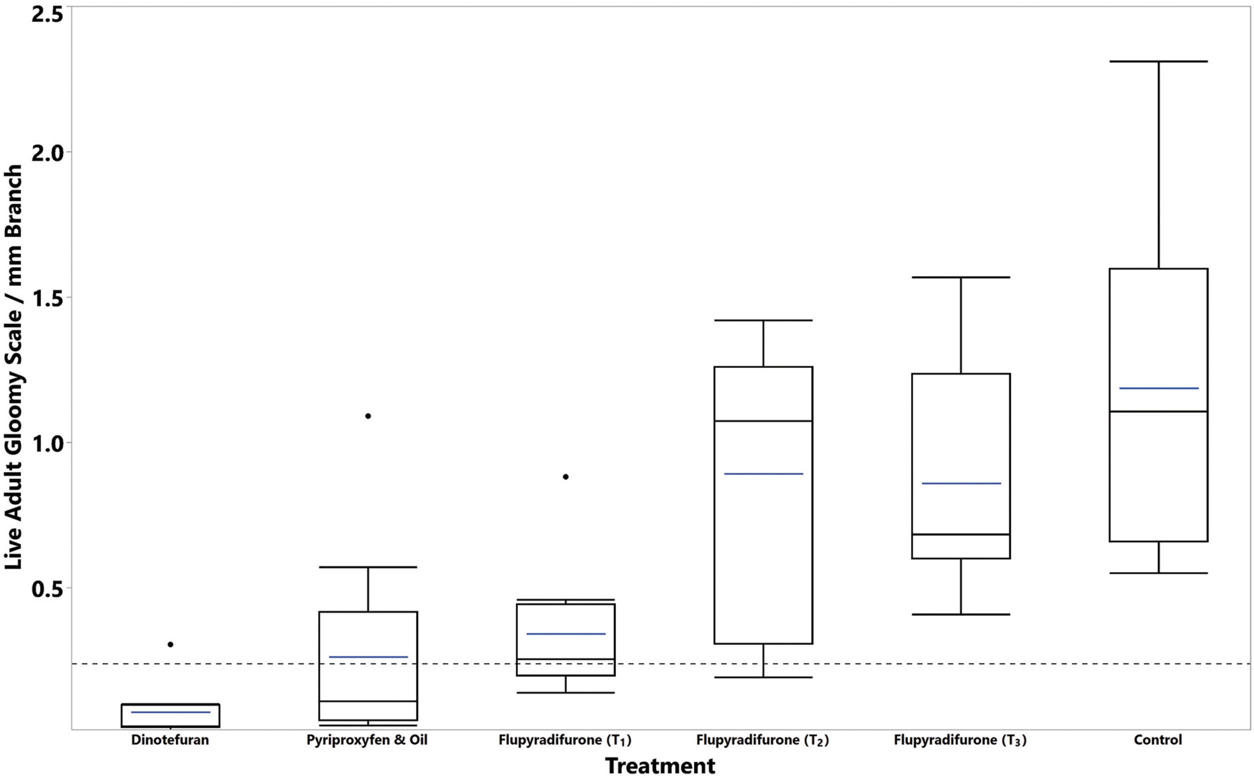

Figure 1. Efficacy of dinotefuran, pyriproxyfen and oil, and flupyradifurone against gloomy scale in a trial conducted in Rock Hill, South Carolina, USA in 2019. Treatments arranged by ascending sample mean. Refer to Table 1 to obtain date of treatment application. The blue line and black line within each box represent the mean and median, respectively. The dashed horizontal line at 0.24 on the y-axis represents the satisfactory suppression line, which is 80% reduction from the control mean.

Table 2. Gloomy scale density summary statistics from a product trial conducted in Rock Hill, South Carolina, USA in 2019.

Treatment	*N*	Mean	SD	SE	Median	95% CI	Minimum	Maximum
Dinotefuran	9	0.07	0.09	0.03	0.02	0.01–0.13	< 0.01	0.3
Pyriproxyfen plus oil	9	0.26	0.35	0.12	0.11	0.03–0.50	0.03	1.09
Flupyradifurone T_1	9	0.34	0.23	0.08	0.26	0.19–0.49	0.14	0.88
Flupyradifurone T_2	9	0.89	0.48	0.16	1.07	0.58–1.21	0.19	1.42
Flupyradifurone T_3	9	0.86	0.39	0.13	0.68	0.60–1.12	0.41	1.57
Control	9	1.19	0.57	0.19	1.11	0.82–1.56	0.55	2.31

RESULTS

The one-way ANOVA revealed that treatment was a significant predictor of GS density ($F_{5,48}$ = 11.52, P < 0.0001). The post-hoc Dunnett's test revealed the dinotefuran, pyriproxyfen plus oil, and flupyradifurone T_1 treatments were significantly different (i.e., lower GS density) from the control treatment (Figure 1; Table 2). Of these 3 most efficacious treatments, trees treated with dinotefuran had the lowest GS densities. The flupyradifurone T_2 and flupyradifurone T_3 were the least efficacious and were not statistically differentiable from untreated controls. See Table 2 for summary statistics.

The average number of live GS adults on control-treated trees was 1.19/mm branch. In agricultural systems, a "satisfactory" level of suppression is generally considered 80% reduction of a pest. Therefore, the "satisfactory" threshold of residual live GS for this study based on the control treatment (mean of 1.19) is 0.24. Dinotefuran was well below this threshold with a mean of 0.07 GS adults/mm branch. Both pyriproxyfen plus horticultural oil and flupyradifurone T_1 were just above this threshold at 0.26 GS adults/mm branch (78% suppression) and 0.34 GS adults/mm branch (71% suppression), respectively (Figure 1).

DISCUSSION

Red maple is one of the most popular tree species for planting in the urban landscape in North America. Its widespread use in these stressful environments can lead to major health concerns. Likely, the most widespread and damaging pests of ornamental and landscape red maples in the southeastern and mid-Atlantic US is GS, often requiring intervention with insecticidal products. Consistent with current recommendations by several state extension services, we found that dinotefuran and pyriproxyfen plus horticultural oil can reasonably be considered effective treatments for GS management when applied during crawler activity. Additionally, flupyradifurone may be considered to be an efficacious treatment if applied during crawler activity. While we found that treatments of flupyradifurone applied post-crawler period were ineffective, we did not test any product prior to crawler emergence, which should be considered in future trials.

Of the 3 products tested at the time of crawler emergence, dinotefuran was the most consistently efficacious, with a 96% reduction in GS density relative to controls and the smallest 95% confidence interval of all treatments. These data certainly align with recommendations from extension services for the use of products containing this active ingredient. The systemic nature and application method options (usually foliar-, soil-, and bark-applied) for dinotefuran-containing products make these particularly attractive for GS management. Also, the longer expected residual of soil- and bark-applied dinotefuran covering the extended GS crawler emergence/activity period may explain why this product had the lowest number of alive adults.

While not strictly reaching the 80% reduction mark, pyriproxyfen plus horticultural oil was still found to have adequate levels of GS density reduction (78%). This treatment appeared to suffer from greater amount of variation in efficacy than dinotefuran when considering standard deviation, standard error, 95% confidence intervals, and the range of densities counted (minimum and maximum values; Table 2). This combination of products relies heavily on (1) appropriate timing of application and (2) adequate coverage on the tree, as the insecticidal activity of these products requires contact. While these are disadvantages of this particular treatment, these products are generally considered environmentally friendly.

Flupyradifurone, while also technically not achieving the 80% reduction mark, can be considered effective at suppressing GS crawlers when they were active, but was not effective when scale crawlers had settled. Flupyradifurone is favorable because the product is deemed "bee safe" (Glaberman and White 2014) and can be applied to flowering plants in accordance with the label. However, some studies have found that acute exposure to high doses impairs bee cognition, taste, and olfactory learning (Tan et al. 2017; Hesselbach and Scheiner 2018). Mixing flupyradifurone with triazole fungicides also increases bee toxicity and should never be practiced (Bayer Crop Science AG 2013; Tosi and Nieh 2019). Furthermore, despite some visitation by early-season pollinators (e.g., Batra 1985), red maple is considered to be a primarily wind-pollinated species and flowers very early in the season. The application of products for GS management should occur post-flowering, further limiting pollinator exposure.

We found active and settled crawlers on 29 May when 1352.5 growing degree days (GDD)(base 50 °F/10 °C) had accumulated according to GreenCast®

(Growing Degree Days 2020). The only listed GDD crawler emergence period to the authors' knowledge is 1500, according to the New Jersey Department of Agriculture (Horticultural pests of regulatory concern, Vol. III: Scale insect pests [Accessed 2020 February 13]). Existing scientific literature (e.g., Frank et al. 2013) and information from state extension services note that product interventions should occur at the time of crawler activity for optimal efficacy. Therefore, the difficulty in managing this insect likely stems from issues with product application and the timing of crawler emergence and activity. Primarily, mistimed applications and/or the extended GS crawler emergence period of 6 to 8 weeks could result in crawlers being exposed to sublethal residual levels of product.

Like all product applications, utilizing a product that has the least negative effect on local flora and fauna while suppressing the pest population of concern is the primary goal. While it may be necessary to apply an insecticidal product to reduce a heavy infestation of GS, the long-term goal of an Integrated Pest Management (IPM) program is to maintain pest populations below a damaging threshold. In this system, the most vulnerable red maples to GS infestation are those present in urban environments with poor cultural conditions and exposed to abiotic stresses. Addressing these issues, such as improving soils through decompaction and making necessary amendments (Fite et al. 2011), removing girdling roots that prevent water and essential nutrients from moving to the canopy, and practicing proper irrigation, may help urban trees increase vigor and ward off secondary pests such as GS, but further research needs to be conducted.

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Kevin D. Chase (corresponding author)
Bartlett Tree Research Laboratories
13768 Hamilton Road
Charlotte, NC, USA
717-353-4258
kchase@bartlett.com

Elden LeBrun
Bartlett Tree Research Laboratories
Charlotte, NC, USA

Chad M. Rigsby
Bartlett Tree Research Laboratories
The Morton Arboretum
Lisle, IL, USA

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The authors reported no conflicts of interest.

Résumé. La cochenille lugubre (CL)(*Melanaspis tenebricosa*) est un ravageur important de l'érable rouge (*Acer rubrum*) dans une grande partie de l'est des États-Unis. Les traitements actuellement recommandés pour le contrôle de CL sont efficaces lorsque les applications sont effectuées au moment approprié. Toutefois, il n'est pas toujours possible d'intervenir au moment adéquat. Par exemple, le propriétaire de l'arbre peut ne pas contacter les professionnels de la lutte antiparasitaire à temps pour faire le traitement au bon moment. Nous avons mis en place un essai sur le terrain afin de déterminer l'efficacité des pesticides pyriproxyfène jumelé à de l'huile horticole et dinotéfurane, ainsi qu'un pesticide relativement nouveau disponible sur le marché des plantes ligneuses ornementales, le flupyradifurone, contre la CL. Cette étude avait trois objectifs principaux: (1) comparer quantitativement l'efficacité du pyriproxyfène jumelé à de l'huile horticole et le dinotéfurane; (2) comparer le flupyradifurone avec ces deux traitements généralement recommandés; et (3) évaluer si le flupyradifurone est efficace lorsque les applications sont faites tardivement dans l'été. Nous avons constaté que les applications de pyriproxyfène jumelé à l'huile horticole, dinotéfurane, et flupyradifurone effectuées pendant la période d'activité des chenilles étaient aussi efficaces, statistiquement mais que les traitements au flupyradifurone appliqués plus tard dans l'été n'étaient pas statistiquement distincts des contrôles non traités. Bien que ces applications de pesticides soient efficaces pour supprimer les populations de CL, les tactiques de soins phytosanitaires visant à prévenir les épidémies devraient être priorisées et intégrées dans la stratégie de lutte globale contre les ravageurs.

Zusammenfassung. Die Mehltau-Schildlaus (*Melanaspis tenebricosa*) ist ein bedeutender Schädling des Rot-Ahorns (*Acer rubrum*) in weiten Teilen der östlichen USA. Die aktuellen Pestizidempfehlungen für die Bekämpfung der Mehltau-Schildlaus sind wirksam, wenn die Anwendung zum richtigen Zeitpunkt erfolgt. Der richtige Zeitpunkt ist jedoch nicht immer möglich. So kann es beispielsweise vorkommen, dass sich der Baumbesitzer nicht rechtzeitig mit einem Schädlingsbekämpfer in Verbindung setzt, um eine rechtzeitige Anwendung durchzuführen. Wir haben einen Feldversuch angelegt, um die Wirksamkeit der Pestizide Pyriproxyfen plus Gartenbauöl und Dinotefuran sowie eines relativ neuen, auf dem Markt für Ziergehölze erhältlichen Pestizids, Flupyradifuron, gegen die Mehltau-Schildlaus zu bestimmen. Es gab drei Hauptziele dieser Studie: (1) die Wirksamkeit von Pyriproxyfen plus Gartenbauöl und Dinotefuran quantitativ zu vergleichen; (2) Flupyradifuron mit diesen beiden allgemein empfohlenen Behandlungen zu vergleichen; (3) zu beurteilen, ob Flupyradifuron wirksam ist, wenn die Anwendungen später im Sommer erfolgen. Wir fanden heraus, dass Pyriproxyfen plus Gartenbauöl (Dinotefuran und Flupyradifuron), die während der aktiven Crawler-Periode angewendet wurden, statistisch gesehen gleich wirksam waren, und dass Flupyradifuron-Behandlungen, die später im Sommer angewendet wurden, sich statistisch nicht von unbehandelten Kontrollen unterschieden. Während diese Pestizidanwendungen bei der Unterdrückung von Mehltau-Schildlaus-Populationen wirksam sind, sollten Pflanzenschutzmaßnahmen, die auf die Verhinderung von Ausbrüchen abzielen, Vorrang haben und in die gesamte Schädlingsbekämpfungsstrategie integriert werden.

Resumen. La escama gomosa (GS)(*Melanaspis tenebricosa*) es una plaga importante del arce rojo (*Acer rubrum*) a través de gran parte del este de EE. UU. Las recomendaciones actuales sobre plaguicidas para el manejo del GS son eficaces cuando se realizan aplicaciones en el momento adecuado. Sin embargo, el momento adecuado puede no ser siempre posible. Por ejemplo, el propietario del árbol puede no ponerse en contacto con los profesionales de gestión de plagas a tiempo para hacer aplicaciones oportunas. Establecimos un ensayo de campo para determinar la eficacia de los pesticidas piriproxifeno más aceite hortícola y dinotefuran, así como un pesticida relativamente nuevo disponible en el mercado de plantas leñosas ornamentales, flupyradifurone, contra GS. En este estudio se buscaron tres objetivos principales: (1) comparar cuantitativamente la eficacia del piriproxifeno más el aceite hortícola y el dinotefuran; (2) comparar flupyradifurone con estos dos tratamientos generalmente recomendados; y (3) evaluar si la flupyradifurone es efectiva cuando las solicitudes se realizan más adelante en el verano. Encontramos que las aplicaciones de piriproxifeno más aceite hortícola, dinotefuran y flupyradifurone, realizadas durante el período de oruga activa, eran igualmente eficaces, estadísticamente y que los tratamientos de flupyradifurone aplicados más adelante en el verano no eran estadísticamente diferenciables de los controles no tratados. Si bien estas aplicaciones de plaguicidas son eficaces para suprimir las poblaciones de GS, las tácticas fitosanitarias destinadas a prevenir los brotes deben priorizarse e incorporarse a la estrategia completa de gestión de plagas.