APPLICATION OF SYSTEMIC INSECTICIDES IN RELATION TO BOXWOOD LEAFMINER'S LIFE HISTORY

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Abstract. We describe the life cycle of boxwood leafminer (*Monarthropalpus flavus*) in the mid-Atlantic region of the United States in relation to growing degree-day accumulations. In addition, the efficacy of three systemic insecticides (avermectin, imidacloprid, and acephate) for control of the boxwood leafminer were evaluated. Avermectin and imidacloprid applied at adult flight provided excellent control. Imidacloprid applied in the summer when larvae were present in leaves gave good control of larvae. Avermectin and acephate were ineffective when applied in the summer.

Key Words. Boxwood leafminer; *Monarthropalpus flavus*; American boxwood; *Buxus sempervirens* 'Arborescens'; degree-days; monitoring; systemic insecticides; avermectin; imidacloprid; acephate.

The boxwood leafminer (*Monarthropalpus flavus* (Schrank)) is a key insect pest of boxwoods in both nurseries and landscapes (Gagne 1989). A survey of residential landscapes in Maryland, U.S., revealed that boxwoods accounted for 8.7% of the total woody plants encountered and the boxwood leafminer was the third most common insect pest requiring control (Holmes and Davidson 1984).

Cultivars of American boxwood (*Buxus sempervirens* 'Arborescens') are severely damaged by this insect. Larvae mine parenchyma tissue of boxwood leaves. Mined leaves become discolored and blistered. In heavy infestations, leaves senesce and drop prematurely, thus rendering the canopy thin and unsightly. This in turn reduces the aesthetic quality of the plant. Heavily infested plants are more susceptible to cold injury and winter-kill (Johnson and Lyon 1988; Batdorf 1994) and attract predatory birds that rip open the galls to eat the larvae (Batdorf 1994). Birds can remove many of the miners, but collateral damage from feeding is often worse than that of the leafminers (d'Eustachio 1999).

Historically, treatments for this pest included applications of molasses plus nicotine sulfate, fumigation with hydrogen cyanide gas, or even dipping smaller plants in hot water. Sulfur dusts and applications of arsenic directed at adults resulted in minimal and moderate success, respectively. A combination of prolonged adult emergence and removal by wind and rain limited the success of sulfur dusts and molasses-based sprays (Hamilton 1925). Due to its high toxicity to insects and good residual activity, DDT was the first material to provide outstanding control of this pest (Runyon 1945; Barnes 1948).

Several materials including nicotine sulfate, lindane, malathion, dimethoate, carbaryl, and diazinon have been used as foliar treatments (Shread 1970). The proper timing of insecticide treatments is most important when attempting to kill adults (Hamilton 1925; Brewer et al. 1984; Batdorf 1994; Relf and Appleton 1994).

More recent control methods have focused on applications of insecticides to control larvae mining in leaves (Shread 1970; Brewer et al. 1984; Batdorf 1994). Triclorfon, propoxur, and chlorpyrifos all provided effective control of larvae (Shread 1970). Brewer et al. (1984) tested Soldep, pirimiphos-methyl (Actellic), and omethoate (Folimat) and found pirimiphos-methyl provided reasonably good control.

The objectives of this study were twofold. First, we described the life history of the boxwood leafminer in the mid-Atlantic region of the United

States in relation to growing degree-day (GDD) accumulations. Second, we determined the efficacy of commonly used systemic insecticides applied at two times, adult emergence and larval development, in reducing densities of boxwood leafminers on boxwoods in landscape settings.

MATERIALS AND METHODS

Growing degree-day models are important tools for predicting pest activity and timing-control tactics for many pests of woody plants in landscapes (Davidson and Raupp 1999; Shetlar and Herms 1999). Although several methods are available for calculating GDD accumulations, we selected the averaging method for its simplicity (Davidson and Raupp 1999; Shetlar and Herms 1999). Any arborist or landscape manager can use this method to determine GDD accumulations with a minimum–maximum thermometer and simple calculator. Fifty degrees Fahrenheit (10°C) is a threshold temperature conventionally used in this calculation (Davidson and Raupp 1999; Shetlar and Herms 1999). Because average daily temperatures usually do not exceed 50°F in January and February at our study sites, March 1 was selected as the date at which temperature measurements and GDD determinations commenced. To calculate GDD for a given day, we used the mathematical equation: GDD = ((max + min)/2) – threshold temp, where GDD = growing degree-days, max = daily maximum temperature, min = daily minimum temperature, and threshold temperature = 50°F (10°C) (Davidson and Raupp 1999). At each of two locations, Longwood Gardens, in Kennett Square, Pennsylvania, and the United States National Arboretum in Washington, DC, weather stations equipped with recording thermometers were used to record daily minimum and maximum temperatures. Degree-days were measured for 2 years at Longwood Gardens during the growing seasons of 1994 and 1995 and for one growing season, 1995, at the National Arboretum.

To quantify the development of boxwood leafminers from egg to adult, we collected 20 leaves from 10 plants at Longwood Gardens and three plants at the National Arboretum. To help reduce variation associated with differences in leaf age, leaves of the same plastochron index were selected. Leaf samples were dissected to determine the stadium of the immature stages. Adult emergence was noted by recording the number of plants with swarming adults. Life history events of the boxwood leaf miner were then described mathematically as GDD expressed in terms of means and standard errors.

The second phase of this study was conducted during 1994 with established plantings of *Buxus sempervirens* 'Arborescens' at Longwood Gardens. We evaluated the efficacy of foliar systemic pesticides applied at different stages of boxwood leafminer development. The first trial compared an application of avermectin (Avid®, emulsifiable concentrate) with one of imidacloprid (Merit®, wettable powder) early in the growing season at the time of adult emergence and flight. The second trial examined the effect of later applications of avermectin, imidacloprid, and acephate (Orthene®, wettable powder) when early instar larvae were in leaves.

For the first trial, 15 plants were selected and randomly assigned to one of three treatments: Five received an application of avermectin, five received an application of imidacloprid, and five received an application of water (control). All treatments were applied at the first sign of adult emergence in late April 1994. Both avermectin and imidacloprid were used at concentrations recommended for leafminer control, 0.7 mL/L (0.1 oz/gal) for avermectin, and 3.75 g/L (0.5 oz/gal) for imidacloprid. An adjuvant (Tween®) was added to each tank of insecticide mix and to the water control at the rate of 0.66 mL/L (0.17 oz/gal). Each plant was sprayed to a point slightly beyond leaf drip using a 7.6-L (2-gal) compression hand sprayer.

Approximately 5 months after the application of insecticides, in September, treated plants were sampled to assess oviposition behavior and survival of larvae in treated and control plants. Boxwood leaves attacked by the female fly bear a distinct scar on the undersurface of the leaf where the female inserts her ovipositor and deposits an egg (d'Eustachio 1999). Oviposition scars were used to identify leaves attacked by the leafminer. Ten leaves bearing oviposition scars were removed from each plant, and the number of oviposition scars was counted. Each excised leaf was dissected, examined microscopically, and the number of living larvae recorded.

The second insecticide trial was initiated in mid-July 1994 to evaluate the efficacy of systemic insecticides applied later in the growing season. Twenty plants selected for this trial were randomly assigned to one of four treatments: Five received an application of avermectin (Avid®), five received an application of imidacloprid (Merit®), five received an application of acephate (Orthene®), and five received an application of water (control). Insecticide rates for avermectin and imidacloprid were the same as those used in the previous trial, and acephate was applied at the rate of 3.75 g/L (0.5 oz/gal). An adjuvant (Tween®) was added to each tank of insecticide mix and to the water control at the rate of 0.66 mL/L (0.17 oz/gal). Each plant was sprayed to a point slightly beyond leaf drip using a 7.6-L (2-gal) compression hand sprayer.

Oviposition activity on each plant at the time of the application of insecticides was estimated by removing ten infested leaves from each plant and recording the number of oviposition scars on each leaf. Approximately 3 months after the application of insecticides, in mid-September, we removed, dissected, and microscopically examined ten infested leaves from each plant. In each leaf, we counted the number of living larvae. Larval survival and oviposition data were analyzed with a one-way analysis of variance and a Student-Newman-Keuls test to separate treatment means (Zar 1999).

RESULTS AND DISCUSSION

Development of boxwood leafminer in relation to GDD accumulations is reported in Table 1. Laboulbene (1873) and Brewer et al. (1984) provided detailed descriptions of the morphology and life cycle of the boxwood leafminer. Our observations concur with these accounts. Emergence of adults flies correlated well with the spring flush of leaves, much like that of other leafminers such as the holly leafminer *(Phytomyza ilicicola)* (Potter and Kimmerer 1986; Potter and Redmond 1989). The first appearance of boxwood leafminer adults occurred at 352 GDD and peak emergence was at 440 GDD. This corresponded to late April and early May. Adults were bright orange, delicate flies that looked like small orange mosquitoes. Leafminer adults were very noticeable against the dark green background provided by mature boxwoods.

The ephemeral adults quickly mated and laid eggs. Female boxwood leafminers have a sharp, pointed ovipositor to insert their eggs into the underside of boxwood leaves. Oviposition can take from 3 to 8 minutes (Hamilton 1925). Oviposition produced a distinct scar that was visible to the naked eye on the underside of the leaves. This scar was very useful in assessing oviposition activity of females and can be used by IPM technicians as a monitoring aid. The first eggs were observed at 352 GDD, but the peak number of eggs was observed at 748 GDD in mid-May. Females lay eggs exclusively in the new growth. Eggs of the leafminer were small, gelatinous, translucent, and about the size of a leaf parenchyma cell. They were placed deeply into the leaf tissue through the abaxial surface of the leaves. Hamilton (1925) estimated that females lay an average of 20 eggs each. The deposition of eggs into new growth may be a mechanism to ensure that larvae have a high-quality food source (Raupp and Denno 1983). Potter and Kimmerer (1986) observed that holly leafminer development was closely linked to the presence of various structural and chemical defense mechanisms in holly. More-

Table 1. Life stages of the boxwood leafminer *(Monarthropalpus flavus)* in relation to growing degree-day (GDD) accumulations and phenological events of boxwood.

Life stage	First occurrence (GDD)	Peak occurrence GDD mean (SE)	Julian dates (approximate)	Phenological event
4th instar	0	80 (27)	March–April	Large galls, discolored, blistered leaves
Pupa	46	310 (66)	April – May	Bud burst, emergence windows and exuviae on leaf undersides
Adult	352	440 (127)	April–May	Shoot elongation, young leaves with oviposition scars
Egg	352	748 (104)	May	Same as previous stage
1st instar	679	1106 (258)	June	Leaf maturation
2nd instar	1236	2459 (270)	June–September	Gall initiation
3rd instar	2443	3287 (161)	September–March	Gall enlargement

over, several authors have suggested that leafminers and gall-formers successfully colonize plants with meristematic tissue or when young leaves are present (Washburn and Cornell 1981; Potter and Kimmerer 1986; Potter and Redmond 1989). Brewer (1981) found that larval survivorship decreased significantly if adults were forced to wait 1 to 2 weeks after leaves had expanded before they were allowed to lay eggs. This was possibly due to the leaves being too old and tough for leafminers to utilize effectively.

Boxwood leafminer eggs first hatched at 679 GDD and peaked at 1106 GDD in early June. First-instar larvae were horseshoe shaped and relatively featureless. Second-instar larvae first appeared 1,236 GDD and peaked at 2,459 GDD and were distinguishable by the larvae "straightening out" and enlarging.

The formation of a leaf gall coincided with the development of the second instar and the molt to the third instar in August. Hypertrophied cells were visible in the parenchyma layer of leaves. By mid-August, the gall became apparent as a pair of tiny bumps proximal and distal to the central vein of the leaf on either side of the oviposition scar.

Third-instar larvae first appeared at 2,443 GDD and peaked at 3,287 GDD. This stage was marked by the appearance of the sternal "breastbone" or spatula clearly visible through the cuticle of the insect. Third-instar larvae continued to grow and develop through the fall and winter months, and there appeared to be little winter mortality.

By March when sampling resumed, some larvae had already molted to the fourth instar. Therefore, the first appearance date for fourth-instar larvae is 0 GDD (Table 1). The peak occurrence of this stage was at 80 GDD. The key feature of this stage, the ventral breastbone, became notably longer and formed a distinctive "T" shape at its posterior end. This coincided with the most prominent damage to the leaves. Leaves became yellow, orange, or brown as galls grew to their full size.

Opening a gall revealed specialized tissue clearly visible to the naked eye. Larvae were quite large (~2 mm) and writhed when disturbed. Examination under the microscope revealed an eversible head, mouthparts, and a pair of single-segmented antennal tubercles. As fourth-instar larvae completed their development, they carved a small, one-cell-thick "window" in the underside of the leaf.

Fourth-instar larvae pupated in mid-April. Pupae first appeared at 46 GDD, with a peak occurrence at 310 GDD. Pupae were light orange in color and darkened as they matured. Pupae moved about if disturbed. Eyes, antennae, and wingpads turned light red to near black as development progressed.

At the completion of the pupal stage, pupae pushed their way out of the gall through the window and hung by their posterior end. Adult flies emerged through a suture in the thorax. Brewer (1981) found that adult emergence usually occurred in the first few hours of daylight. Adults emerged quickly and were completely free of the pupal case in about 10 minutes. Within 5 minutes of emergence, wings expanded and the adult was able to fly.

The application of imidacloprid at the time of adult emergence significantly reduced the number of oviposition scars made on boxwoods (Figure 1) ($P < 0.017$). We do not know whether the reduction in the level of oviposition was the result of a direct lethal effect of imidacloprid or due to a repellent effect on females. Both avermectin and imidacloprid proved highly effective in reducing the number of larvae found in boxwood leaves (Figure 2) ($P < 0.01$). When avermectin and imidacloprid were applied at the first appearance of adults, leafminer populations were reduced more than 85%. If flight of adult leafminers cannot be observed, then applications of avermectin or imidacloprid at 352 GDD, with a March 1 start date and 50°F (10°C) threshold should provide excellent control.

When avermectin, imidacloprid, and acephate were applied in July, only imidacloprid significantly reduced boxwood leafminer populations ($P < 0.03$) (Figure 3). Boxwoods treated with imidacloprid had about 80% fewer larvae than those treated with avermectin or acephate, or the untreated controls. Lack of efficacy could be due to leaves "hardening off" to a point where avermectin and acephate were unable to penetrate the waxy leaf surface.

In summary, we have documented the development of boxwood leafminer in landscape settings in the mid-Atlantic region of the United States in relation to GDD. We demonstrated that proper timing and selection of chemicals significantly reduced leafminer populations. This information should be useful for arborists and plant health care technicians to monitor and control the boxwood leafminer.

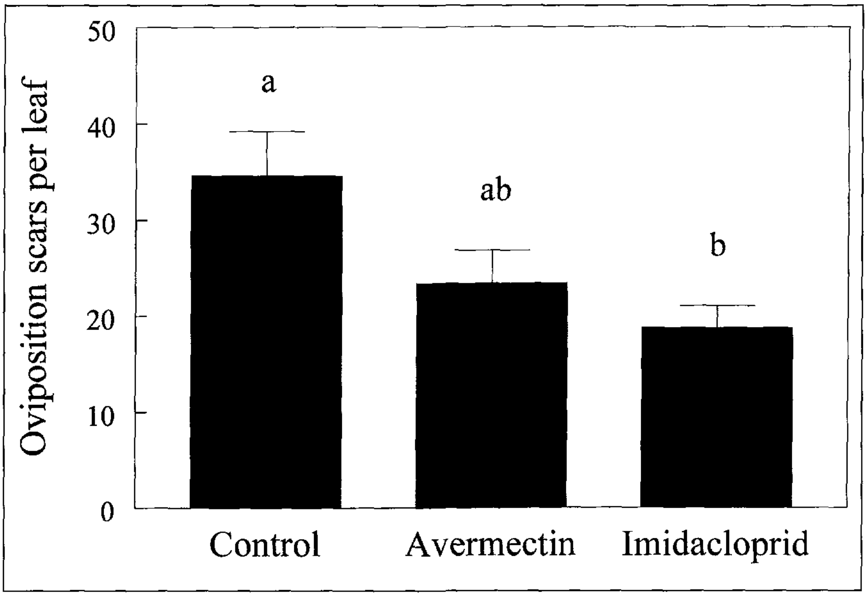

Figure 1. Effect of avermectin and imidacloprid applications on the number of oviposition scars per leaf made by boxwood leafminers on *Buxus sempervirens* 'Arborescens'. Bars represent means, and vertical lines represent standard errors. Means that share the same letter do not differ by a Student-Newman-Keuls test, $P = 0.05$.

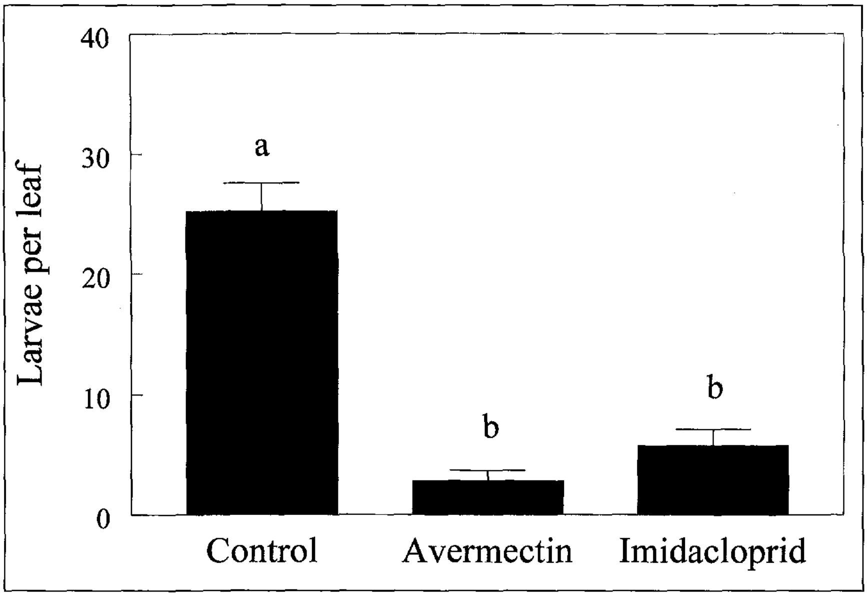

Figure 2. Effects of spring applications of avermectin and imidacloprid made at the first appearance of boxwood leafminer adults on the number of larvae found in each leaf of *Buxus sempervirens* 'Arborescens'. Bars represent means, and vertical lines represent standard errors. Means that share the same letter do not differ by a Student-Newman-Keuls test, $P = 0.05$.

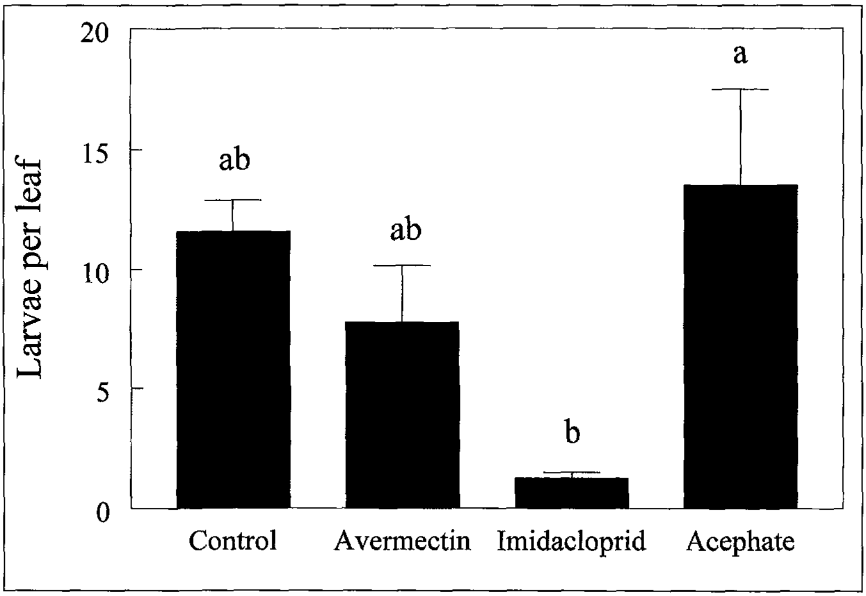

Figure 3. Effects of summer applications of avermectin, imidacloprid, and acephate on the number of boxwood leafminer larvae found in each leaf of *Buxus sempervirens* 'Arborescens'. Bars represent means, and vertical lines represent standard errors. Means that share the same letter do not differ by a Student-Newman-Keuls test, $P = 0.05$.

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Résumé. On décrit le cycle de vie de la mineuse du buis dans la région de la côte atlantique des États-Unis en relation avec l'accumulation des degrés-jour. De plus, l'efficacité de trois insecticides systémiques (avermectin, imidacloprid, acephate) pour le contrôle de la mineuse du buis ont été évalués. L'avermectin et l'imidacloprid appliqués au stade de vol des adultes a fourni un excellent contrôle. L'imidacloprid appliqué en été lorsque les larves étaient présentes dans les feuilles a produit un bon contrôle de ce dernières. L'avermectin et l'acephate étaient inefficaces lorsque appliqués en été.

Zusammenfassung. Wir berichten über das Leben des Hartriegelbohrer in der mittleren Atlantikregion der USA im Vergleich ihrer Wachstum bzw. Tagesakkumulation. Zusätzlich wurde die Effektivität von drei systemischen Insektiziden (Avermectin, Imidacloprid, Acephat) zur Kontrolle des Hartriegelbohrers bewertet. Avermectin und Imidacloprid bringt ausgezeichnete Kontrolle beim Ausflug der erwachsenen Insekten. Imidacloprid erzeugte eine gute Kontrolle der Larven, wenn die Larven im Sommer an den Blättern auftauchen. Avermectin und Acephat waren bei Anwendung im Sommer ineffektiv.

Resumen. Se describe el ciclo de vida del minador boxwood en la región Atlántica de los Estados Unidos con relación a las acumulaciones diarias-grado de crecimiento. Además fue evaluada la eficacia de tres insecticidas sistémicos (avermectin, imidacloprid, acephate) para el control del minador. Avermectin y imidacloprid aplicados en insectos adultos proporcionaron control excelente. Imidicloprid aplicado en el verano cuando estaban presentes las larvas en las hojas dieron buen control. Avermectin y acephate no fueron efectivos cuando se aplicaron en verano.