Pome Fruit Arthropods
IOBC/wprs Bulletin Vol. 30 (4) 2007
pp. 37-42

Biology and management of woolly apple aphid, *Eriosoma lanigerum* (Hausmann), in Washington state

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Abstract: Woolly apple aphid, *Eriosoma lanigerum* (Hausmann) (Homoptera: Aphididae) has become a more severe pest in Washington apple production in the past few years. Milder winters have promoted overwintering survival on the aerial parts of the tree. A very low percentage of the current apple acreage is planted on resistant rootstocks, nor are such rootstocks used for new plantings. The transition from organophosphate insecticides to either insect growth regulators or neonicotinyl insecticides may also be contributing to higher pressure. In addition, this pest became one of quarantine concern in 2006. Alternatives to organophosphate pesticides have been tested for several years. Of these, petroleum oil shows some promise, as does a particle film used for sunburn protection. A neem-based insecticide provided temporary suppression, as did several neonicotinyl insecticides. A second approach to management, that of controlling the root colonies, was explored for the first time in this region. In potted tree assays, several compounds including imidacloprid, spirotetramat and oxamyl showed good root and systemic activity; in field trials, however, results were more variable. A greenhouse test of 8 clonally propagated rootstocks and 2 seedling rootstocks demonstrated that several of the new Geneva rootstocks to have virtual immunity to a Washington strain of woolly apple aphid, whereas the older Malling-Merton rootstocks had a lesser degree of antixenosis.

Key words: woolly apple aphid, host plant resistance, selective insecticides

Introduction

Woolly apple aphid, *Eriosoma lanigerum* (Hausmann) (Homoptera: Aphididae), is a pest of apple world wide. It is native to eastern North America, where it used American elm (*Ulmus americanum* L.) as the primary host. This pest was spread to other growing regions throughout the globe beginning as early as the mid-1700s, before quarantine measures were conceived, let alone implemented. Early American entomologists originally imputed this species to the Old World, until the association with American elm was found, identifying it as a New World species (Patch, 1912). Its reputation for devitalizing trees earned it the nickname of "American Blight" by European entomologists.

The case of woolly apple aphid and its primary parasitoid, *Aphelinus mali* Haldeman, is one of the notable early examples of classical biological control (DeBach ,1964; Asante and Danthanaryana, 1992). *A. mali* is also native to eastern North America. Parasitized aphids were shipped to many of the countries around the world where woolly apple aphid had become established. In most cases, establishment of *A. mali* was also successful, although the degree of control it exerted was more variable.

Woolly apple aphid has been classed as a serious pest in Washington since the industry began in the late 1800s. According to early writers, the introduction of *A. mali* in 1931 effectively demoted its status to a minor pest (Yothers, 1947). Early efforts at biological control with *A. mali* were considered a success, and the occasional outbreak treated with nicotine compounds. DDT disrupted biological control, and problems became more severe after World War II. The transition to the organophosphates (primarily for codling moth), probably provided a significant degree of suppression of woolly apple aphid. The current transition away from organophosphate insecticides may be part of the reason for the increasing incidence and severity of woolly apple aphid populations in Washington. In addition, milder winters may have allowed more survival in the aerial parts of the trees, and more rapid establishment in the post-dormant period.

While the increase in woolly apple aphid incidence would be a minor concern to pest management programs, its status as a quarantine concern has elevated it to a more serious level. In February of 2006, China stopped shipments from two Washington packing houses because of the presence of woolly apple aphids in either the stem or calyx end of the apples. The interest in controlling this pest rose proportionately.

Woolly apple aphid control in Washington is currently a combination of chemical and biological control. The reasons for success or failure of biological control are not well understood; however, more recent work in Washington (Walker, 1985) indicated that the predator complex may play a greater role than previously thought. Resistant rootstocks played somewhat of a role in the past, but the Malling-Merton 100 series are no longer planted. Control has been aimed exclusively at the aerial colonies; the reservoir on the roots, both its role in perpetuating populations and its effect on the trees, has been largely ignored.

Material and methods

Phenological studies

The phenology of 1st instar (crawlers) of woolly apple aphid migration was studied in 2005 and 2006. Commercial orchard blocks were selected on the basis of a previous history of infestation and the use of a selective insecticide program. Crawler movement was studied using two sticky bands on the main tree trunk. The lower band was about 15 cm above the soil surface and trapped the crawlers moving upward from root colonies. The upper band was about 1 cm above the lower band, and trapped crawlers moving downward. However, since both bands interfered with normal establishment of colonies in the aerial portions of the tree, presumably the data on downward movement is less representative than that of upward movement. Bands were constructed of a 3-cm strip of aluminum foil held in place with spray-on adhesive. A thin bead of Tree Tanglefoot was applied to the center of the band. Bands were checked ca. weekly from bloom until frost by removing them from the trees, placing them in plastic bags, and counting the crawlers under a stereomicroscope.

Rootstock evaluations

Apple rootstock liners, 6-10 mm diameter, were planted in a soil mixture of equal parts peat, pearlite, and vermiculite on 21 April. Ten rootstock types were used: The Geneva line 4210, Geneva 41, Geneva 202, Bud (Budagovsky) 9, Bud 118, M.9 (Malling 9), M.26, MM.111 (Malling-Merton 111), seedlings from Washington (Willow Drive Nursery), and seedlings from New York. Ten replicates of of each rootstock were planted. Trees had approximately 6 cm of new shoot growth before infestation.

Insects were collected from a commercial orchard in East Wenatchee, WA. Stem sections 4-6 cm long, each with 50-200 aphids, were placed at the base of each tree on 19 May. First instars were observed on the trees the following day. Fresh stem sections were collected on 22 May and placed on any trees that appeared to have a low number of first instars. This included all of Geneva 41, Geneva 202, 4210, and about half of the other trees. Trees were arranged on a greenhouse bench in a randomized complete block design (10 rootstocks × 10 replicates).

Aphids had matured by 8 June and had begun to produce new first instars Trees were evaluated on 16 June using a numeric rating system on a scale of 0 to 4, where 0=no infestation, 1=very few (1-2) small colonies; 2=few (3-8), small colonies; 3=moderate number of normal-sized colonies; 4=large, coalesced colonies. The rating was done by unaided visual inspection of the whole tree.

Insecticide tests, aerial colonies

Airblast tests were conducted in commercials orchards in central Washington. Plots consisted of 5-10 trees in single rows, with buffer rows separating treated rows. Three woolly apple aphid shoot colonies per plot were tagged. Trees were sprayed with an airblast sprayer at 100-200 gallons per acre. Live and parasitized aphids were counted in the tagged colonies pre- and post-treatment until densities in the check were low.

Handgun tests were conducted in a similar manner to the airblast tests, except the plot size was smaller (1-2 trees), and trees were sprayed to drip with a handgun sprayer operated at 200 psi.

Data were analyzed using the Statistical Analysis System (SAS 1988). Data were tested prior to analysis for homogeneity of variance using Levene's (1960) test. Variances found to be non-homogeneous were transformed [ln(y+0.5)] before analysis. PROC GLM was used to conduct an analysis of variance, and treatment means were separated using the Waller-Duncan *k*-ratio *t*-test.

Potted tree bioassays

2005 Bioassays. Two bioassays were conducted in a greenhouse on potted apple trees (September and December). Seedling apple trees (12 mm diam) were planted in 15-cm diam pots. Soil was gathered from a commercial orchard near Quincy, WA. Uncultivated soil was taken from the side of block. The soil was primarily sand and silt (Shano series [mixed, mesic Xerollic Camborthids]). Trees were potted in 1.5 liters of one part soil and one part pearlite. After trees had grown shoots approximately 15 cm long, twigs from infested trees were placed on the branches. After a few weeks, aphids were well established and had formed shoot colonies. At that time about 0.5 liters of soil in the pots was removed to expose part of the roots to the new mobile aphids. Crawlers settled on the roots by crawling down from shoots or from infested twigs.

Twenty-four trees were selected for each bioassay. Woolly apple aphid were counted on all shoots. All exposed aphids on the roots were counted, then the missing soil mixture was replaced. Trees were distributed into four replicate blocks based on the population of woolly apple aphid on the roots, then treatments were randomly assigned within each block. Spirotetramat was applied to the foliage (2 times, 2 wk apart) to run-off with a 3.78-liter sprayer. Water for this treatment was first acidified to a pH of 6-7 with a few drops/liter of 1N HCl. All other products were applied as soil drenches. Trees were fully watered three days before application, then 250 ml of insecticide solution was poured onto the soil. This volume completely saturated the soil in the pots. Starting three days after treatment, trees were watered regularly, but minimal water was lost through the drainage holes of the pots. Shoot colonies were assessed periodically for 4 wk after the second application, then all trees were lifted, the soil gently washed from the roots, and root colonies assessed.

2006 Bioassay: This bioassay was done as described above except trees were potted in a mixture of equal parts peat, pearlite, and vermiculite.

Insecticide tests, edaphic colonies

Three commercial orchard blocks in central Washington were chosen for a previous history of woolly apple aphid infestation. One block (PR) had made a post-harvest treatment for aphids in the fall of 2005, and had no aerial colonies in May of 2006. However, viable aphid colonies were found regularly on root suckers. A second orchard (MV) consisted of ca. 25-yr-old 'Fuji' apples, and had a large population of aphids overwintering on the aerial parts of the tree. The third block (BT) had had heavy infestation of aphids for the past several years, but no visible colonies at the time of application.

Treatments were applied in mid-May with a boom sprayer calibrated to deliver ca. 100 gallons per acre. Insecticides were applied to the herbicide-treated strip under the trees in a band ca. 1.2 m wide on either side of the trunk. While all orchards received regular herbicide applications, the degree of weed infestation in the herbicide strip varied among the blocks. The day before application, the trees were given a full irrigation set (ca. 12 h) and allowed to drain overnight. After the insecticides were applied, irrigation water was turned on for about 45 min to help move the insecticides into the soil profile.

Woolly apple aphid populations crawler movement was evaluated using a single sticky band (described previously). Based on previous experience, the single band was likely most indicative of upward crawler movement, thus providing a measure of control of the root colonies. Three trees per plot were banded. Crawlers were counted and fresh bands were applied at 2-3 wk intervals from May through August. In addition, numbers of woolly apple aphid aerial colonies were assessed with a 3-min count at intervals throughout the season. The timed search spanned the entire plot, omitting the banded trees.

Results and discussion

Phenological studies

Numbers of upward-moving crawlers was higher than downward movement in most of the orchards studied. In 2005 (when only one orchard was studied), migration began in early May, peaked in early June, and returned to low levels by mid-July. In 2006 (three orchards studied), the peak of upward crawler movement was shifted later in the season by 4-6 wk, peaking in late June to mid-July. The timing of downward movement of crawlers was roughly the same as upward movement, but about 75% few individuals were caught. However, as mentioned previously, the interference of the bands in the establishment of aerial colonies could be partly responsible for the weaker downward movement.

Rootstock evaluation

Differences among the different rootstocks in degree of woolly apple aphid infestation were apparent within a few week of artificial infestation. After 4 wk, the susceptible rootstocks (including M.9, M.26, Bud 9, Bud 118, and seedlings from New York and Washington) were heavily infested. Colonies had coalesced on the worst trees, producing copious amount of woolly filaments. On MM.111, the 'Northern Spy' derived resistant rootstock, colonies were small and poorly developed, but woolly apple aphids had established successfully. On the Geneva 'Robusta 5' derived resistant rootstocks (G.202, G41, and 4210), the majority of the replicates were free from infestation; on the remainder, a few colonies, usually consisting of a very limited number of aphids, had established.

This experiment demonstrated that the East Wenatchee strain of woolly apple aphids used in this test has not overcome the 'Northern Spy'-based resistance, as has been noted in other areas of the world (Gilliomee *et al.*, 1968; Rock and Zeiger, 1974; Sen Gupta and Miles, 1975). This is likely a moot point since it is probable that only a small percentage of

Washington's apple acreage is planted on a resistant rootstock. Both of the most popular rootstocks in the Malling-Merton 100 series (MM.111 and MM.106) have been discarded for more dwarfing and productive rootstocks (e.g., M.9 and M.26). Some of the Geneva series of rootstocks offer a higher level of woolly apple aphid resistance than the Malling-Merton series, and may also have more desirable horticultural characteristics. A highly resistant rootstock may greatly facilitate management of this pest, and possibly improve the likelihood of biological control.

Insecticide tests, aerial colonies

Of the materials tested to date, diazinon has provided the most consistent level of control. Endosulfan has also been quite effective, while the systemic material dimethoate is less so. All of these materials (two of which are organophosphates) are older compounds, and their continued registration on tree fruits is in question. The increase in woolly apple problems, coupled with possible withdrawal of effective materials, makes the search for replacement compounds more urgent.

As a class, the neonicotinyls are not as active on woolly apple aphid as they are on other tree fruit aphid species. Thiamethoxam, imidacloprid and acetamiprid have been tested as foliar sprays; and although they provide a degree of suppression, they do not give control at the same level as the organophosphates. Azadirachtin (neem) provided temporary suppression, but populations rebounded in a few weeks. Of the non-registered materials tested, flonicamid and NNI-0101 showed promise for control of woolly apple aphid. Petroleum oils continue to show promise as a lower-cost, low-impact alternative for woolly apple aphid. However, they also only provide suppression. Best results will likely be obtained with higher rates and higher spray volumes, and possibly repeated applications.

Potted tree bioassays

2005 Bioassays. All treatments, whether applied foliarly (spirotetramat) or as a drench (imicloprid and oxamyl) provided good control of the shoot colonies. Spirotetramat and imidacloprid tended to be a little slower than oxamyl in reducing shoot colonies. At the end of the experiment, all treatments also provided excellent control of root colonies. The unique feature of spirotetramat is its bidirectional translocation within the plant, thus root colonies may be control with foliar sprays.

2006 Bioassay. This bioassay provided more extensive testing of spirotetramat. The material was tested at two rates and with two different adjuvants (methylated seed oil and an organosilicone). An additional material, dinotefuran (a neonictinyl) was also tested as a soil application, with imidacloprid as a standard. All materials provided excellent control of shoot colonies, although the organosilicone adjuvant appeared to provided somewhat faster control.

Insecticide tests, edaphic colonies

Imidacloprid provided the most consistent suppression of crawler movement and mid-summer establishment of aerial colonies. These results echo those of Pringle (1998), who saw several years residual effect from a single imidacloprid application. Oxamyl, which looked equivalent to imidacloprid in potted tree bioassays, failed to show significant control in field trials. A May application of spirotetramat did not affect crawler movement, however, it did suppress aerial colonies in mid-summer. Dinotefuran gave a lesser degree of control. Two experimental treatments, NNP-731 and NNP-732, gave an intermediate degree of control. Two non-insecticidal treatments (sticky bands and insulation foam banded around the trunk) provided no reduction in the numbers of aerial colonies. In several instances, the information from the bands did not correspond well to the degree of shoot infestation.

Acknowledgements
The authors gratefully acknowledge the Washington Tree Fruit Research Commission for funding of these studies. Funding was also provided by Bayer CropScience, Cerexagri, DuPont, Gowan, and Nichino America.

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